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INSTITUTE OF
PAPER CHEMISTRY
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SURVEY OF RECYCLED FIBER USAGE
IN LINERBOARD

Project 2697-3

Report One
A Progress Report
to
FOURDRINIER KRAFT BOARD GROUP
of The
AMERICAN PAPER INSTITUTE

July 1, 1977

THE INSTITUTE OF PAPER CHEMISTRY
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July 15, 1977

Mr. T. J. Gross
The Fourdrinier Kraft Board Group
American Paper Institute
Suite 810,1605 Main Street
Sarasota, FL 33577

Dear Mr. Gross:

PROJECT 2697-3 - REPORT ONE

SURVEY OF RECYCLED FIBER USAGE
IN LINERBOARD

Enclosed is a copy of a progress report on research carried out for the Fourdrinier Kraft Board Group of the American Paper Institute. The objective of this project is to develop methods or techniques by which the optimum use of recycled fiber on linerboard can be achieved without sacrificing board quality or performance. The first phase of the study involved a survey of the technical state of the art. This included a survey of FKBG members, other companies and research groups with regard to recycled fiber usage in linerboard and processing. A review of the literature on recycled fiber systems for linerboard was also carried out. In addition the survey included consideration of raw material availability and economics.

RESEARCH PLAN

In general, the survey indicated that key factors in the research should include consideration of refining, chemical additives, fractionation of recycled fiber into long and short fiber fractions, and the impact of systems such as asphalt dispersion on the efficient and effective use of recycled fibers in linerboard. Pilot plant and commercial evaluation of methods developed in the research are an important part of the research as is evaluation of the effect of contaminants on any new methods developed in the study.

LITERATURE REVIEW

The literature review included consideration of the effects of repulping, fractionation, stock preparation and manufacture. The literature indicates that repulped fibers tend to exhibit lower bonding potentials than virgin fibers. However, these differences in bonding potential can be overcome in whole or part by additional refining, by the use of chemical additives and by wet pressing. Fractionation of old corrugated is being accomplished commercially. The literature and experience indicates that fractionation should have advantages. Improvements in performance effected by wet pressing, additives and new refining techniques are also covered in the survey.

BOARD QUALITY

In general it appeared that linerboards made with various amounts of recycled fiber exhibited commercially acceptable strength levels.

RAW MATERIAL AVAILABILITY

Projections of the manufacture of corrugated containers indicate that in 1985 there will be about 5.1 million tons of old corrugated available for use in linerboard. This represents about 30 percent of the forecasted linerboard production capacity of 17.1 million tons.

ECONOMICS

An analysis was also made of the economics of recycling old corrugated into linerboard. The primary factors considered were the costs of old corrugated, virgin kraft pulp, capital and transportation. This analysis indicated that the use of old corrugated may be feasible up to national average recycling rates of about 3.4 million tons without considering capital savings. Consideration of the latter would encourage higher recycling rates.

If you have any questions concerning the report, please contact us. We welcome your comments, criticism or experience relevant to this study.

Yours very truly,

Bill Whitsitt

William J. Whitsitt
Research Associate
Container Division

WJW/mck
Enclosure

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

SURVEY OF RECYCLED FIBER USAGE IN LINERBOARD

SUMMARY

A research program to optimize recycled fiber use in linerboard has been initiated at the Institute in cooperation with the Fourdrinier Kraft Board Group of the American Paper Institute. Increased use of recycled fiber in linerboard will assist the industry in reducing needs for new capital investment, keeping pollution abatement costs down and in conserving energy and natural resources.

The objective of this project is to develop methods or techniques by which the optimum use of recycled fiber in linerboard can be achieved without sacrificing board quality or performance. These processes have to be compatible with existing linerboard process systems, and have to result in at least equivalent productivity when compared with existing systems.

The first phase of the study involved a survey of the technical state of the art. This included a survey of FKBG members, other companies and research groups with regard to recycled fiber usage in linerboard, and processing. A review of the literature on recycled fiber systems for linerboard was also carried out. In addition, the survey included consideration of raw material availability and economics. The survey findings are briefly summarized below.

1. Research program. Based on the survey, the following subjects were considered important:

   a. Refining of recycled fiber is a key factor to be considered in the research.

   b. The use of additives, both swelling and bonding agents, deserves an important place in the research.

c. Fractionation of fibers in recycled materials may be advantageous.

d. The impact of systems such as the asphalt dispersion system on the effective and efficient use of recycled fibers should be carefully evaluated.

e. The research work should include laboratory, pilot plant and full scale commercial evaluations.

f. Recycled fiber contaminants are very important and their effects on any new techniques have to be considered.

2. Mill process systems. The eleven operating systems which were surveyed, had many similarities, however there were considerable differences from mill-to-mill in types of cleaning and screening equipment and their arrangement in the process. Several systems were compared including Flote-Purge and low intensity pulping. In general, the high users of recycled fiber had more cleaning and screening equipment than the mills using lower quantities of recycled fiber as a supplementary furnish. However, most mills reported some difficulties with build-up of petroleum base contaminants on equipment, appearance and board quality. Slippery liner and strength problems were mentioned. One of the mills was successfully operating a system to fractionize old corrugated into long and short fiber fractions. The long fiber was used in linerboard and the short fiber on medium.

3. Board quality. Linerboard samples made with various amounts of recycled fiber up to 100% were evaluated for strength properties. In general it appeared that the linerboards made with various amounts of recycled fiber exhibited commercially acceptable strength levels when appropriately processed.

4. Literature review. The survey included consideration of the effects of repulping, fractionation, and stock preparation and manufacture. The studies carried out by several investigators indicate that repulped fiber differs significantly from virgin fibers in many respects. The loss in bonding potentials appears to be most critical. However, these differences in bonding potential can be overcome, at least in part, by additional refining, by the use of chemical additives and by increased wet pressing.

Fractionation of old corrugated is being accomplished commercially. The literature and experience indicate that fractionation should have advantages.

5. Raw material availability. Projections of the manufacture of corrugated containers (potential OCC) indicate that in 1985 there will be about 5.1 million tons of OCC available for use in linerboard. This represents about 30% of the forecasted 1985 linerboard production of 17.1 million tons.

6. Economic impact. An analysis was also made of the economics of recycling OCC into linerboard. The primary factors considered were the costs of OCC, virgin kraft pulp, capital and transportation. This analysis indicated that the use of OCC may be feasible up to national average recycling amounts of about 3.4 million tons without considering capital savings. Consideration of the latter would encourage higher recycling rates.

INTRODUCTION

The Fourdrinier Kraft Board Group (FKBG) has had an active interest in the use of recycled fiber in linerboard for many years, and for many different reasons. Approximately one year ago, working with the staff of the Institute, the Technical Division started to develop research plans on this project, titled "Optimization of Recycled Fiber in Linerboard." It was agreed that increased use of recycled fiber in linerboard would assist the industry in reducing needs for new capital investment, in keeping pollution abatement costs down, and in conserving energy and natural resources.

The objective of this project is to develop methods or techniques by which the optimum use of recycled fiber in linerboard can be achieved without sacrificing board quality or performance. These processes have to be compatible with existing linerboard process systems, and have to result in at least equivalent productivity when compared with existing systems.

The first phase of the study involved a survey of the technical state of the art. This included a survey of FKBG members, other companies and research groups with regard to recycled fiber usage in linerboard, processing methods, board qualities and problems. A review of the U.S. and foreign literature on regular fiber systems for linerboard was also carried out. In addition the survey included consideration of raw material availability and economies. The survey findings are summarized in this report.

A part of the first phase, the tentative research plan originally submitted was modified to incorporate some of the survey findings. The survey indicated that the research plan (dated 3/15/77) is basically sound and acceptable to the FKBG membership.

SURVEY OF STATE OF ART

LITERATURE REVIEW

In preparing this review extensive use was made of the following Institute of Paper Chemistry bibliographies:

1. Reclaimed Fibers. Bibliographic Series No. 248, 1971.
2. Reclaimed Fibers. Bibliographic Series No. 248, Supplement I, 1975.

These were supplemented by a search of the Abstract Bulletin of The Institute of Paper Chemistry for the more recent period through 1976. Inasmuch as the literature is extensive and dates over many years no claim is made for completeness although it is believed that the survey has included the more important recent literature. Primary attention has been focussed on factors affecting the strength and drainage characteristics of recycled fiber with particular reference to the utilization of recycled fiber from old corrugated containers in kraft linerboard.

It should be recognized that the literature on such subjects as processing, refining and chemical additives is very extensive and much of it has been directed to the behavior of virgin fiber stocks. No attempt has been made to review these subjects in detail for this survey. Similarly it was believed to be beyond the scope of this survey to catalog the many types of cleaning, screening and refining equipment used in the paper industry on a worldwide basis.

Effect of Recycling

The effects of repulping on the strength properties of the paper or board made from recycled fiber furnishes have been studied by a number of investigators. Pfaler (1), using a furnish corresponding to newsprint, found that repulping decreased bursting strength by about 16%, tensile strength 10%, and tearing strength approximately 6%.

Brecht (2) carried out an extensive study to determine the effect of repulping on a furnish consisting of Northern unbleached sulfate pulp without the addition of size and filler. The results showed that for equivalent beating time the repulped stock was always freer and the resulting sheets were less dense and more absorptive than those prepared from the same stock initially. Tensile strength, fold endurance and internal tearing resistance were usually considerably below the original values, the only exception being very "slow" papers. Brecht attributed these changes to loss of fines. He noted that the essential properties of the original sheet could be maintained through several repulpings when a small amount of fines was added each time to the stock. Wet pressing of repulped stock increased the density and many strength factors to a certain extent; however, the test levels achieved with increased wet pressing were not equal to the results obtained originally. Thus, it appeared that the use of high wet pressing did not replace in full the role played by the fines.

McKee (3) studied the effect of repulping through six cycles on the properties of the stock and paper made therefrom. Virgin unbleached kraft was employed as the starting furnish. When the stocks were refined to constant freeness on each cycle significant changes in the papermaking characteristics of the fiber occurred. Figure 1, which illustrates a portion of his results, shows that the degree of swelling of the fibers and the transverse bonding strength of the sheets decreased markedly with the number of repulping cycles. For example, the degree of swelling was about 12% lower than the virgin reference after one cycle and about 36% lower than the virgin after six cycles. The swelling characteristics are of considerable importance because, as the fiber swells, it increases in exposed area, deformability and flexibility, all of which are conducive to more intimate contact between fibers in drying and, hence, better bonding. Figure 1 also shows that the fiber strength as measured by the zero span tensile test decreased moderately due to recycling and only modest decreases on bonded area were obtained.

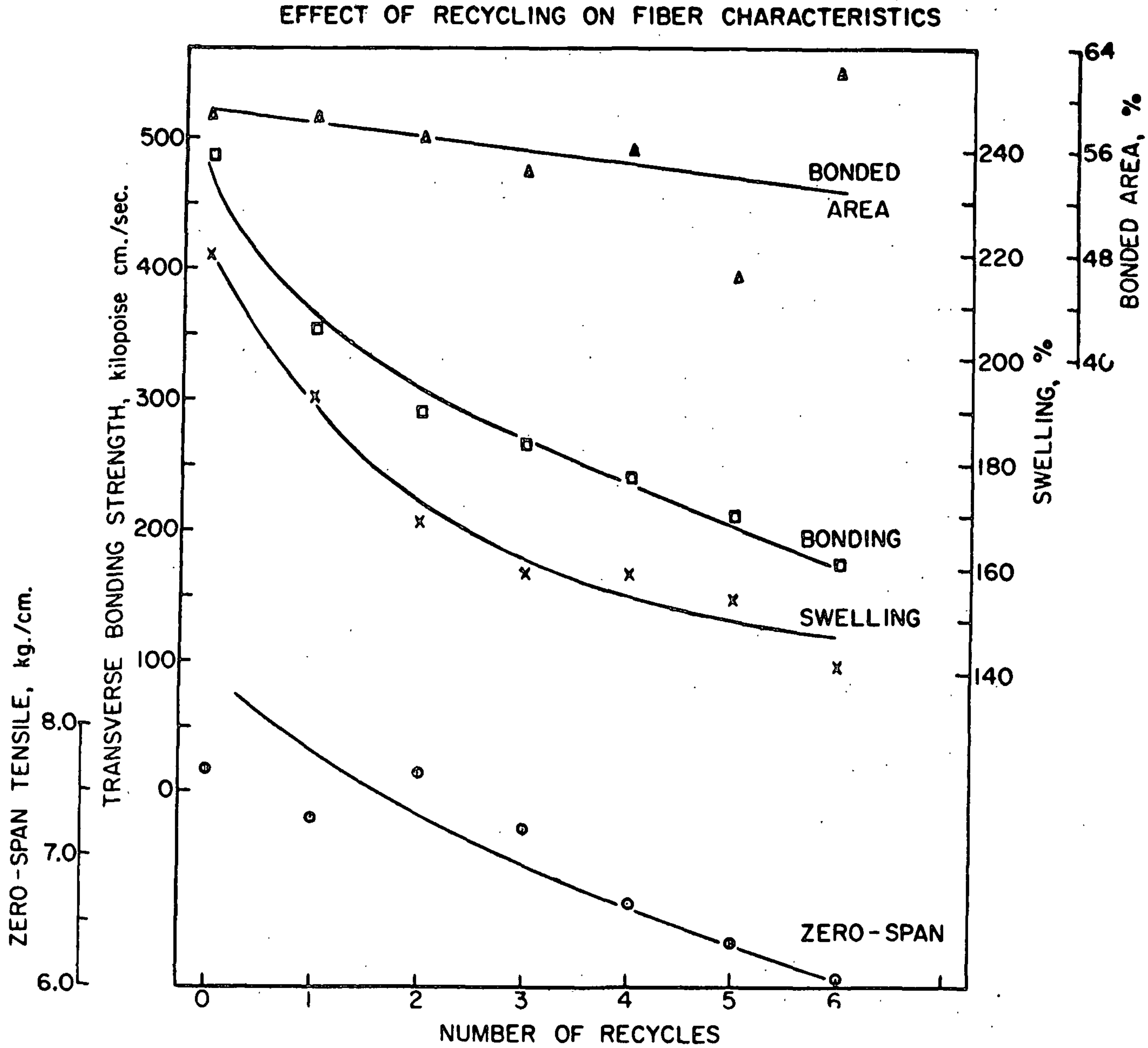


Figure 1. Effect of Recycling on Fiber Characteristics [From Ref. (3)]

Figure 2, also based on McKee's work (3), shows the effect of recycling to a constant freeness on a number of sheet properties. Apparent density decreased by about 13% after six cycles. For a given pulp, density may be considered as an indirect indication of the degree of refining and, hence, bonding. It may be noted that the decrease in apparent density and presumably fiber bonding is accompanied by a marked decrease in bursting strength and tensile strength. Bursting strength which is a function of the tensile and stretch characteristics of the sheet decreased by about 14% after one cycle and approximately 38% after six cycles.

In contrast, at constant freeness tearing strength increased with number of repulpings. Tearing strength is dependent on the work required to (a) rupture individual fibers in tension and (b) pull individual fibers out of the fiber network (4). In general, the work required to pull out fibers is greater than the work to rupture fibers. The less strongly the fibers are bonded the fewer will be the number of fibers ruptured and a greater number will be pulled out. An increase in the number of fibers pulled out will result in a higher tearing strength. In this case the apparent density and transverse bonding strength decrease with number of recycles, hence tearing strength would be expected to increase because more fibers are being pulled out and fewer are being ruptured.

McKee concluded that recycled fibers refined to the same degree in terms of freeness exhibit lower fiber strength and bonding potentials than the same fiber in the virgin state. Furthermore, he notes that those sheet properties which are dependent on fiber-to-fiber bonding and fiber strength decrease markedly with the number of repulpings at constant freeness.

McKee also noted, however, that these findings do not indicate that board made with recycled fibers will always have inferior strength characteristics.

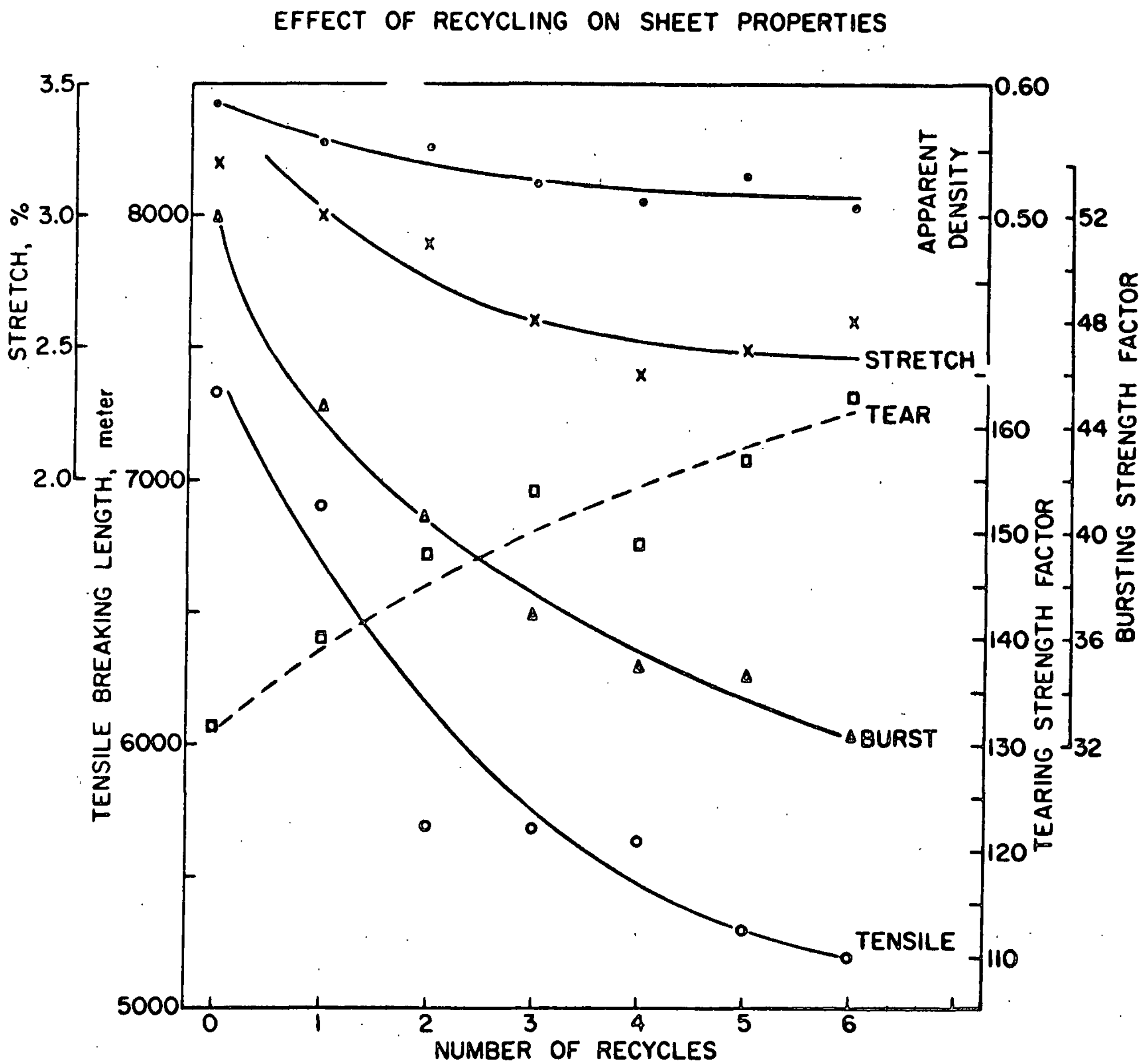


Figure 2. Effect of Recycling on Sheet Properties [from Ref. (3)]

Increased bonding and sheet strength may be obtained in a number of ways — i.e., by additional refining or the use of additives. As an illustration, repulped kraft handsheets were made from stock refined to 500, 375, and 300 cc and compared to sheets made from the virgin stock at 600 cc freeness. In general, burst and tensile strengths equal to or better than the virgin sheet were obtained due to the additional refining. However, as would be expected, tearing strength decreased markedly.

In a later paper, McKee (5) extended the above work to illustrate the effects of recycling to a constant level of strength development rather than to a constant freeness. For this purpose the bursting strength obtained with the virgin kraft pulp at a freeness of 585 cc was used as the reference. On each recycling the repulped stock was refined to the extent necessary to obtain the reference bursting strength level. At constant bursting strength, the apparent density, tensile strength, and transverse bonding strength (ZDT strength) increased on successive recycles while tearing strength and average fiber length decreased. The edgewise compression strength and Taber stiffness of the sheets remained essentially constant on successive recycling under these conditions. However, repeatedly refining fibers to the same bursting strength results in a substantial penalty in terms of freeness. In order to obtain the same bursting strength on successive recycles the freeness levels were decreased from 585 cc for the virgin stock to 455 cc on the first cycle, 345 cc on the second cycle, 250 cc on the third cycle, 190 cc on the fourth cycle, and 90 cc on the fifth cycle. McKee noted that latter freeness levels are impractical because of the adverse effect on machine speed due to the slow drainage rate.

Cildar and Howarth (6) studied the effect of increasing recycling rates from 0.25 to 0.75 using handsheets made from bleached sulfite. Their results indicated that tensile strength decreased rapidly with the number of repulping cycles while opacity did not show any change. The loss in tensile strength was about the same as obtained by McKee (3). Based on zero span tensile tests the authors concluded that losses in tensile strength because of repulping were primarily due to the bonding contribution rather than fiber strength losses in accord with McKee's findings. Their experimental findings did indicate that tearing strength decreased and passed through a minimum on successive repulpings.

Horn (7) examined the effects of repulping on various strength properties using never dried virgin unbleached pine kraft and bleached northern softwood kraft pulps. In one series of experiments the stocks were refined to a constant Canadian Standard freeness of 285 ml on each recycling. In a second series the stock was "not refined after the first cycle, size was not added and the freeness was allowed to float." Horn found that tensile and bursting strength decreased rapidly through the first three cycles and then decreased more slowly on further recycling. He attributed these losses in strength primarily to a loss on bonding potential of the fibers due to changes in fiber flexibility and conformability during the repulping cycles. These findings were further supported by the fact that z-direction tensile strength (an indirect measure of bonding) was more adversely affected by recycling than fiber strength. These conclusions are similar to those obtained by McKee (3,5).

Horn found that tearing strength increased through the second recycle but then decreased. The initial increase was explained in terms of the theory of tearing strength proposed in Ref. (4) by Van den Akker. The decrease in tearing strength after the maximum at the second cycle was attributed to losses in fiber length due to the strong cutting action of the type of refining used as well as the loss in bonding on recycling.

Horn also noted that density decreased on recycling at constant freeness. His results also indicated that rosin sizing had a deleterious effect on the strength properties during recycling. However, treatment of the recycled pulp with 0.5% NaOH tended to restore the strength levels which were lost due to sizing.

Bovin, et al. (8) studied the effect of repulping using bleached and unbleached chemical pulps as well as a mechanical pulp. In general, their findings for the chemical pulps were similar to those obtained by McKee (3,5). Thus, at constant freeness, the breaking length, density and air resistance decrease with number of recycles. The tear factor, light scattering coefficient and light absorption coefficient increase with number of cycles. At a constant breaking length the density and tear factor remain sensibly constant on recycling, however, the drainage resistance (freeness) is drastically increased on each such recycle. On the other hand, most of the properties of the mechanical pulp were constant on successive recycling. These differences in behavior between the chemical and mechanical pulps were believed to be due to the fact that the "lignin-rich" pulp's fiber structure is affected much less by drying. They further indicated that improvements in strength of recycled fibers may be effected by (a) alkaline treatments, (b) careful beating, and (c) increased wet pressing.

Koning and Godschall (9) carried out a study to determine the effects of repeated recycling on the strength and performance of paperboard and corrugated boxes using a pilot plant paper machine and corrugator to make the board. The 100% recycled fiber 42-lb linerboards were made in two ways, namely, (a) without refining so as to maintain the drainage as high as possible and (b) after refining to obtain a bursting strength level of about 100. Recycled fiber mediums were also made and combined with the refined and unrefined recycled linerboard. It may be noted that strength additives were not employed in the study in combination with or as a substitute for refining. For the conditions used the authors concluded that recycling generally lowered the strength properties of the recycled linerboard, medium and corrugated boxes made therefrom. (Note: The box compression results exhibited considerable variation from cycle-to-cycle depending on the box size, orientation and test conditions and, in some instances, the box strength levels were about equal to or higher than the virgin control.) The authors noted that "these reductions (in strength properties) can be overcome to a large extent by refining but with a possible decrease in attainable production rates." In this connection it is believed that the case of chemical additives in combination with refining provides an alternative way of attaining satisfactory strength levels with recycled fibers. The authors also noted that the greatest strength losses occur on the first recycling. Part of this loss was attributed to the NSSC in the recycled combined board and part to recycling. This suggests that fractionation of the recycled fiber into long and short fractions may be advantageous as discussed in later pages.

As would be expected Koning and Godshall reported that repeated recycling caused poorer drainage on the paper machines. Impact performance of the recycled boxes was lower in an edge drop test with can filled boxes. With regard to scoring they indicated that the moisture conditions at time of scoring and folding were more important than the type of board. However, the combined boards made with refined linerboards showed a greater tendency to crack at the score lines than the unrefined linerboards.

Briefly summarizing, there appears to be general agreement that recycled fibers differ significantly from virgin fibers (and papers made therefrom) in many of their properties. The loss in bonding potentials appears to be most critical. In general at constant freeness the properties of the paper which are mainly dependent on fiber bonding and strength decrease markedly with the number of times the fiber is recycled. Furthermore, when the recycling is carried out at a given strength level — e.g., bursting strength — it has been found that it is necessary to refine to progressively lower freeness in each recycling. Thus, on successive recycling the freeness and fiber length decrease and can reach impractical levels in terms of production rates and sheet performance. One of the primary differences between virgin and recycled fibers appears to be related to the fact that the recycled fibers do not swell as readily in water and, hence, do not bond as well. These differences in bonding potential can be overcome, at least in part, by additional refining, by the use of chemical swelling and bonding agents and by increased wet pressing. Thus, paperboards may be made in whole or part from recycled fibers and exhibit satisfactory commercial quality. This is evidenced by the fact that many mills producing linerboard presently employ significant percentages of recycled fiber (10-13).

Fractionation

The use of pressurized screens with small holes to fractionate groundwood pulps was described by Sternby and Lehman (14). Coppick and Brown (15) noted that the centrifugal action in liquid cyclones caused fractionation of wood pulps. In a discussion of centrifugal cleaners, Woodruff (16) indicated that when the feed consistency is lowered from 0.5 to 0.25% the cleaners act as fiber classifiers to separate long from short fibers or summerwood from spring fibers. He cites data obtained at 0.2% consistency which showed that the accepts had a tear strength of 117 while the rejects had a tear strength of 153. Eriksson (17) patented a curved perforated screen for separating rejects from pulp. Nonclogging characteristics were combined with an effective screening action by using a screen with relatively larger diameter openings and by directing the pulp suspension obliquely against the screen.

Skalecky (18) discussed the fractionation of waste paper stocks prepared from newspapers, magazines and mixed papers. He indicated that fractionation was not economical for these furnishes because the cost of the treatment of the rejects was not compensated for by better mechanical properties of the stock.

Jepsen (19) describes application of the Johnson fractionator in groundwood, kraft pulp and recycled fiber stock preparation systems. The Johnson fractionator is essentially a spiral-shaped machine in which the stock is introduced at the center of the spiral. As the spiral is revolved stock is transported to the outer spiral rings. During this transportation process fibers in the stock move at different rates depending on size and, hence, are classified according to size. Means are provided in the discharge so that fractions having selected size ranges are segregated.

Jepson (19) noted that in the case of groundwood the fractionator can be used to separate the pulp into two parts — one containing mostly long fibers and the other containing the short fibers and fines. If the long fiber fraction (65% of total) only is refined, the author indicates that about a 15% increase in strength (tensile) can be obtained with a considerable saving in refining energy. For kraft pulp three fractions were taken and separately refined. The results indicated that the long fraction could tolerate more refining than either the whole pulp or the other two shorter fiber fractions. Also, the fine fractions developed tensile strength more quickly than either the whole pulp or coarse fraction. When the separately refined fractions were blended together and compared with the whole pulp, a 10-15% improvement in strength (tearing strength data shown) was reported with a saving in refining energy of from 25-30%. The author indicated that the process should also have application in the case of old corrugated furnishes.

Olgard and Axenfalk (20) reported on a number of pilot scale trials using the Johnson fractionator. The furnishes investigated included kraft pulp, semichemical pulp, groundwood, mixed recycled paper, old corrugated and eucalypt pulps. In general, the results obtained are similar to those reported by Jepson (19). In the case of old corrugated the authors indicate that the fractionator can separate out a long fiber fraction corresponding essentially to that included in the original linerboard. This fraction can be refined to strength levels which compare favorably with virgin kraft. The authors indicate this fraction is intended to be used as the top liner stock in one Scandinavian mill making test liner. In general, for all the pulps studied the authors indicated that "the separately refined and remixed pulps exhibit better paper properties compared to the original conventionally refined pulps." They also reported savings in refining energy of about 20% for chemical pulp.

Clark and Iannazi (21) reported on a process developed at A. D. Little, Inc. which separates old corrugated into two fractions, namely, a long fiber fraction and a short fiber fraction. In essence the process involves a controlled size reduction of the recycled furnish followed by a short soak period. Ideally the linerboard is retained in relatively large pieces so it can be screened out while the medium is defibered and passes through the screen. No commercially operating system of this type has been reported in the literature. Also, comments received during the course of the mill survey indicated that one effort to implement the process on a commercial basis was unsuccessful.

With respect to the performance of the fractionated stock, Clark and Iannazi (21) compared the bursting strengths of the long (liner) and short fiber (medium) fractions with that for the "whole box." At the higher freeness levels (e.g., 600 cc) the long fiber fraction exhibited higher bursting strengths than the "whole box" furnish. In addition, at a freeness of 600 cc the long fiber fraction exhibited higher tensile and tearing strengths than the "whole box" furnish.

Clark and Iannazi (21) estimated that the processing costs for their process would be relatively small compared to the potential added value of the separated stocks. In another article in Paperboard Packaging (22) handsheet data supplied by A. D. Little, Inc. was cited showing that the liner fraction gave higher tensile, burst and tearing strength than the composite corrugated. The article indicated that liner and medium could be made from the long and short fiber fractions, respectively, which would be "essentially equivalent in quality to products made from virgin fiber." Capital and investment costs were also compared for 100% virgin kraft and 100% recycled fiber linerboard mills. The comparison indicated that a higher return on investment could be achieved by the recycled fiber operation primarily due to lower investment costs per ton of product.

Seifert and Long (23) compared seven methods of upgrading recycled old corrugated. The methods investigated were selective pulping, centrifugal cleaning, pressurized digestion, atmospheric digestion, pressurized fractionation, and combinations of these methods. The fractionation methods studied were (1) selective pulping (similar to A. D. Little process), (2) use of a centrifugal cleaner, and (3) a pressurized fractionator (screen). Chemical improvement methods included pressurized and atmospheric digestion using caustic soda. Figure 3 shows the improvements in bursting strength (C.S. freeness of 550 cc) as a function of yield of long fiber for the several methods. The authors commented that the results for pressure fractionation were represented by a broad band due to the variety of test conditions employed. They concluded that the pressure fractionation results compared "favorably with selective pulping or centrifugal cleaning." At a long fiber yield of 70% it appears that the improvements in bursting strength ranged from about 15-30% for pressurized fractionation. A combination of pressurized screening and centrifugal cleaning appeared to yield quite high improvements in bursting strength.

A mild pulping of the stock at 100 psi with 4% caustic gave a bursting strength improvement of 40% at 94% yield and about a 55% improvement on the fractionated stock. These were large improvements but the costs of the treatment were relatively high. Based on a cost analysis, the authors concluded that pressurized fractionation should have relatively high return on investment.

Two commercial applications of the process were cited by Seifert and Long (23). In one case, the long fiber was used to produce recycled linerboard while the short fiber was used in the manufacture of corrugating medium. In the second case, the long fiber fraction was used in making recycled fiber linerboard (primarily 42-lb basis weight) and the short fiber was used in the furnish to a cylinder machine making various combination board grades. As mentioned previously, one of the mills visited during the mill survey employs a pressure fractionator to separate old corrugated into long fiber for use in 100% recycled linerboard and short fiber for use in medium.

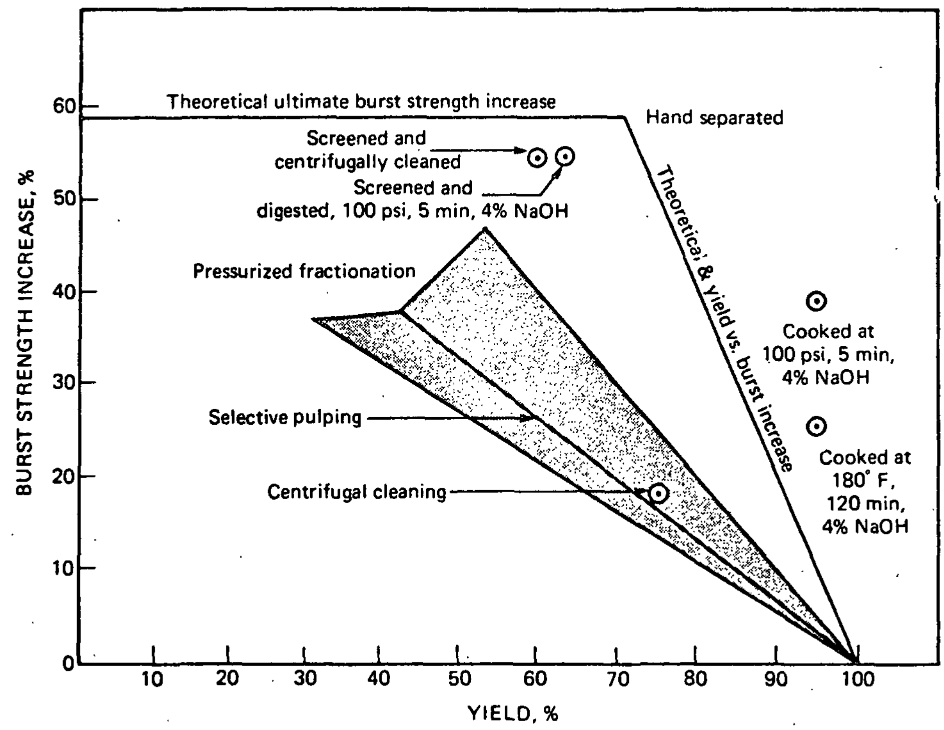


Figure 3. Yield of Fractionated Pulp as Burst Strength Increase, 550 cc C.S. Freeness [from Ref. (23)]

Maynard (24) described two commercial applications involving separation of old corrugated into two fractions, namely, 70% long fiber and 30% short fiber. In one mill operation, the long fiber was used to produce lightweight linerboards or sack paper. The short fiber was used in medium. He commented that the 100% recycled fiber medium made with the short fiber fraction had characteristics which were approximately the same as medium from virgin semichemical pulp, both with regard to physical properties and runnability on the corrugator. In the other mill, the long fiber was also used to make sack kraft and linerboard, while the short fiber was used in the furnish to a cylinder machine. Maynard indicated that both applications were technically satisfactory but have since been shut down — partly because of effluent problems at one mill and partly due to market resistance to products utilizing recycled fiber.

Bolton (25) described a process to fractionate high yield virgin kraft pulps into a 20% accepts fraction suitable for the secondary furnish and an 80% fraction for the primary furnish. A pressure screen having holes less than 0.06-mesh diameter or slots less than about 0.02-inch wide was employed. Carvell (26) also reported on the use of pressure pulp screens to classify pulps according to freeness and particle size. High velocity flow across the surface of the screen plate and high frequency pulsations were noted as necessary to obtain good screening efficiency.

Recently Welshans, et al. (27) studied the recovery of various paper grades by selective wettability. They indicated that the wettability of various papers can be controlled by using various types and concentrations of surfactants. By this means various grades of paper can be separated since the papers can be caused to wet and sink at various times. Presumably this approach could be used to separate the long fiber pine and hardwood semichemical fibers.

Based on the various fractionation studies discussed above it appears that fractionation can be accomplished commercially and should have advantages compared to use of the composite old corrugated assuming both fractions can be used either in linerboard or other products such as medium.

Stock Treatment and Manufacture

One of the primary differences between virgin and recycled kraft softwood fibers is the inability of the latter to swell readily in water. The deficiency in bonding can be overcome by additional refining, by the use of chemical additives such as bonding agents and by wet pressing. Most of the high users of recycled fibers in linerboard find it essential to use chemical agents such as cationic starch in the wet end to achieve satisfactory board quality at practical production speeds. Chase (10) has indicated that it was necessary to increase refining and the amount of beater adhesive from about 1.0 to 1.9 lb/ton as recycled fiber was added to the furnish in amounts up to 21%. Machine speed dropped from 1470 to 1407 fpm on the average during this period. Mohaupt and Koning (28) have shown that an addition of 0.9% ethylated starch at the size press increased the Concora strength of 100% recycled medium by 8 psi although the ring compression strength was not improved.

The literature on the use of wet end adhesives, surface sizing agents, wet strength agents, etc., is voluminous. Swanson (29-31) has reviewed the theory and use of such additives and the following comments are taken from his work. In general, wet end adhesives are usually used to promote bonding in the sheet. This effect may be used to improve dry or wet strength, decrease refining requirements, increase production by faster drainage on the wire, improve formation, etc.

Bonding agents which have the capacity to enhance fiber bonding consist of two classes, namely natural and synthetic bonding materials. The natural bonding agents include such agents as starch and natural gums such as locust bean gum and guar. The latter are naturally occurring mannogalactan gums. These agents are commonly used to increase paper strength and supplement the beater operation.

Swanson (29) provides a comprehensive discussion of the behavior of paper made with such starch and gums as additives.

The synthetic agents include wet strength resins such as urea, melamine and phenol formaldehydes, polyamides and polyacrylamides. The urea and melamine formaldehydes are wet strength agents which are effective under acidic conditions and are also capable of improving dry strength. Phenol formaldehyde resins are used for wet and dry strength improvements. The polyacrylamides can function as a bonding agent or retention aid depending on molecular weight.

Since the practical swelling agents are alkaline materials, their possible use would necessitate the use of an alkaline size. One approach involves addition of internal sizing agents which react with the pulp. Swanson (30) notes that alkyl ketene dimers and substituted succinnic and related anhydrides are used for this purpose (32,33). Another approach involves use of the ammonium salts of styrene maleic anhydride copolymers as surface sizing agents (34).

In a study of the effects of repulping on strength properties, Horn (7) shows that rosin sizing had a detrimental effect on the recovery of sheet strength on recycling. However, the sheet strength was recoverable, at least in part, by treatment of the recycled fiber with 0.5% NaOH. Horn indicated that this was due to the fact that the bonds between the fibers and aluminate resinate are broken under alkaline conditions. Thus, the resinate complex goes into solution "and the fiber surface approximates its original presized condition."

Gleason, *et al*. (35,36) have patented processes for reclaiming pulp from waste paper. These include shredding the paper and subsequently cooking it in solutions containing sodium hydroxide, sodium carbonate, sodium or ammonium carbonate and sodium borate.

The performance of selected drainage aids on liner secondary and primary pulps has been studied under dynamic conditions for the FKBG (37). Polyethylenimine (PEI), a cationic drainage aid and an anionic polyacrylamide resin (PAM) were incorporated into a constant volume of 0.1% consistency stock at addition levels in the range of 0.005 to 2.0% based on fiber resulting in concentrations of 0.05 to 20 parts per million. The time required for drainage was the primary measurement. PEI was found to be an effective drainage aid for the liner secondary pulp under most ionic environments when used at approximately 5-10 ppm under conditions of low agitation and short duration. The greatest increase in drainage rate ($\cong$ 140%) with PEI was accomplished using a synthetic white water system. The lowest increase ($\cong$ 46%) was obtained in a tap water plus alum system. PEI generally had little effect on the drainage properties of the primary pulp although some advantage was indicated in the synthetic white water system.

In general, the polyacrylamide (PAM) resin proved ineffective as a drainage aid under the dynamic conditions utilized on these tests.

Freeness values in the presence of PEI paralleled drainage rates in that both reached a maximum at PEI levels of about 0.5%. However, it was also found that a sizeable difference in drainage rate was obtained at the same nominal freeness depending on agitation rate and time. Hence, floc strength was demonstrated to be an important factor in the liner pulp system.

In a later study (38) for the FKBG, experiments were carried out using various combinations of beater adhesives and drainage aids. On a moderately refined pulp (630 cc CSF) it was shown that 23% improvement in bursting strength was attained through incorporation of 0.5% Kymene 557 (cationic polyamide-polyamine wet strength resin — Hercules Inc.) or through addition of 2% of cationic potato starch (Sta-lok

400) plus 0.03% drainage aid (Nalco 636 — cationic polymer — Nalco Chemical Co.). These strength improvements were achieved with little apparent sacrifice in drainage properties. In general, it appears that such combinations of modest refining plus addition of drainage aid and/or beater adhesive provided a desirable balance in properties.

In general, as fibers are refined, they swell considerably and the specific surface of the fibers increases due to loosening and unraveling of the spirally oriented fibrillar structure of the fiber. The fibers also become more flexible as they are "plasticized" in water. These factors increase the degree of bonding between fibrils and other cellulose fibers when the sheet is formed, pressed and dried. As a result of the increased bonding, such sheet properties as bursting strength, tensile and edgewise compression increase while tearing strength decreases. However, lower sheet strength will result if the beating action is too severe or continued too long.

Danforth (39), in discussing the refining of recycled fibers, notes that the objective of refining recycled fibers are: "to preserve intrinsic fiber strength, develop desired sheet properties and minimize undesirable effects — all at acceptable cost." In a general sense he believes the problem is to determine the severity and number of impacts required to accomplish these objectives. Formulas relating the number and severity of impacts to refining conditions are presented. These indicate, for example, that refiners with relatively few "edges" or relatively high thrust will emphasize fiber cutting. In contrast, a brushing action is achieved with a combination of many "edges" and/or lower thrust. He concluded that recycled fiber furnishes should be exposed to refining conditions involving low fiber cutting and more of a "brushing" action. This can be achieved with tackle elements with a relatively large number of bars to distribute the load over many fibers and to permit the fibers to be impacted repeatedly. Some experimental results using a Claflin refiner are presented to show that various combinations of impact number and severity can produce a given freeness but that the sheet properties will vary.

Saltarelli (40) comments that the outer walls of recycled fiber "have already been exposed or even removed the first time they came through the process." As a result it is difficult to create bonding sites and cohesiveness. He states it is desirable to keep the refining intensity low so as to avoid producing excessive debris. He believes the best way to keep the refining intensity low is to operate the refiner at high speed and have as many bar edges in the filling as possible to keep the power per impact at a low level.

Mathew (41) has discussed efforts to utilize synthetic refiner disc plates so as to achieve the desired surface modification of recycled fibers without reducing the fiber length by cutting. He notes that the modulus of elasticity of the pulp fiber is much lower than that of the metal disc plates usually employed. As a result of this and the refiner design, a wide distribution of force intensity is applied to the fibers. Thus, some will be cut, some severely damaged and others will receive little or no refining action. In an effort to obtain more uniform intensities in the refiner, synthetic disc materials were investigated and results were reported using discs made from modified nylon. Using an old corrugated furnish he indicated that much less fiber length reduction was obtained with the nylon plates. Also at comparable freenesses, the burst and tensile factors were appreciably higher than obtained with conventional steel discs. Tearing strengths were about the same for the two disc materials. He concluded that the use of low modulus refiner discs can provide efficient refining without excessive cutting and that significant improvements in physical properties can be achieved.

Brauns (42) has described the development of the Frotapulper for defibrating and refining stock including recycled fiber. The Frotapulper consists basically of two intermeshing screws which are fed with roughly cleaned stock at about 35% consistency. During passage through the screws the stock is subjected to a kneading, squeezing and rubbing action. This action defibers the stock, rolls plastic materials up into balls that can be screened out in subsequent operations, and separates metals from paper. The stock undergoes a considerable temperature increase — up to about 80°C. In subsequent operations the treated stock is diluted, cleaned and screened to remove plastics and metals. Braums indicates that although a considerable amount of work is performed on the furnish, the strength and drainage do not show any marked change. In general, it appears that the Frotapulper can best be used for combination defibration and initial treatment and followed with conventional refining. Brauns reported that installations have been made in Japan and at the Rena board mill in Norway.

Kenworthy (43) has reviewed recycling developments in Great Britain and western Europe. In the area of machines which perform dual functions of defibering and screening, he mentions the new in-line pulpers, such as the Beloit-Walmsley "Bel-Cor" and the Voith "Turboseparator." Both units accomplish defiberizing and also make it possible to remove light and heavy contaminants. Kenworthy suggests that the total energy requirements (excluding refining) of a system incorporating a Turboseparator are 80% of a conventional high consistency cleaning system.

Continued developments of asphalt dispersion systems in Europe are also reported by Kenworthy. A general problem is that fiber quality tends to be decreased due to such factors as high temperature, coating of the fiber bonding sites with pitch or other petroleum based contaminants, etc. He indicates that the major differences between manufacturers of dispersion equipment lies in the mechanical treatment to disperse the contaminants without doing work on the fiber.

Kenworthy also reviewed the major developments in the area of cleaning and screening equipment. These include slotted baskets in pressure screens as well as centrifugal cleaners with a "vortex seeker" for the light weight contaminants. Tests by PIRA on evaluation of a complete stock cleaning plant at a board mill were also reviewed. The plant had a series of systems consisting of centrifugal cleaners with secondary and tertiary loops, perforated and slotted pressure screens, etc. Both asphalt dispersed and untreated stock were evaluated. It was reported that the overall efficiency of each system, except for stickies, was about 70%. Generally the centrifugal cleaners were most effective, but on film and stickies the "vortex seeker" cleaners made a significant contribution.

Stokes, et al. (44) reviewed developments within the Beloit-Walmsley organization in the treatment of recycled fiber. After citing difficulties encountered with various types of contaminants the experimental facilities at their recycled fiber plant in Bolton were reviewed. These included a hydrapulper, Shark pulping unit, Vortrap, Bird high density cleaner, Bel-Cor defibrator, Vertex disintegrator (Deflaker), Centrisorter, Pressmaster and Shred Master (two disc, high consistency attrition mill). The above facilities are coupled to an experimental Inverform machine. The Bel-Cor, which is normally situated after a high density cleaner, fulfills two functions. First, it removes light contaminants that are not taken out by the ragger in the pulper. Secondly, it acts as a second stage defibering unit. Handsheets taken before and after the Bel-Cor show a fairly large reduction in percentage of undefibered stock despite a relatively low energy input — "as low as 0.24 hp day/ton." The Centrisorter is a pressurized screen development for use at higher consistency (ca 2%) for screening furnishes such as recycled fiber. The authors also comment on water removal and pressing research, asphalt dispersion with particular reference to the Shredmaster, and high consistency processing.

Koffinke (45) has recently discussed the advantages of high consistency processing of recycled fiber. Older systems employing very small holes in the hydrapulper in conjunction with high horsepower, high attrition type rotors are first discussed and then compared with high consistency processing. The latter employs much larger extraction holes in the pulper (0.50-inch diameter or greater) and this reduces both rotor wear and power consumption. A high consistency centrifugal cleaner follows the pulper to protect the deflaking and refining equipment. The next piece of equipment is the Seprafiner — a combination of a defibrator and high consistency perforated screen. It operates in the 3-6% consistency range. He concludes that the high consistency system "eliminates the need for downstream thickening equipment while at the same time supplying a screening and cleaning system which is relatively insensitive to the swings normally found in a stock preparation system."

Woodruff (46) has reviewed the centrifugal cleaning of recycled fibers. For the better grades, small diameter cleaners are generally used in the first and second stages with 6-inch diameter cleaners in the third stage. For heavily contaminated pulps, 6-inch diameter cleaners with the accepts cleaned in smaller diameter units is effective. In general, the ability of centrifugal cleaners to remove contaminants depends on the shape as well as the specific gravity of the contaminants. Separating efficiency improves as the feed consistency decreases but in the primary stage, consistencies below 0.25% may cause fiber classification.

Espenmiller (47) reviewed stock systems of the low intensity pulping type wherein the plastics and other light trash are not ground up into very small pieces. In general, such systems include a pulper, cyclone for high density removal, Selectifier screen and vibrating screen. He also describes a variation of this system with a purge loop in the pulper and systems incorporating fractionating equipment to separate the furnish into long and short fiber fractions. In the latter case the short fiber fraction can be utilized in the manufacture of medium.

As one means of improving strength properties, Chase (10) has reported that modification of the press system in one of their machines to incorporate a third press operating at about 1100 pli allowed operation at record high speeds while still maintaining bursting strength. The use of beater adhesive was also reduced. Lowe (48), in describing the Antioch operation of the Crown Zellerbach Corp., noted that the mill found the best approach to wet pressing was to gradually increase the nip loadings at each position. This increased the fiber bonding and, hence, sheet strength properties. Nip loadings of 350, 450 and 1000 pli are utilized from the first to third press.

Justus and Gustafson (49) have described use of a twin wire former with Converflo headbox to make two-ply and three-ply webs of board. The top and bottom liner during these trials represented about 20-30% of the sheet, depending on the grade weight, and were made up of virgin fiber. The maximum percentage of recycled fiber used in the center ply was 55%. They reported that the test properties of the multi-ply board were comparable to those obtained on board made on a fourdrinier with a secondary head box using virgin fiber.

Klungness (50) investigated the effect of various contaminant removal processes on recycled fiber properties. The contaminant removal processes studied were deinking, aqueous polyethylene removal, polyethylene solvent extraction, hot melt solvent extraction, wet strength removal and asphalt dispersion. He concluded that significant differences in properties of recycled fibers result not from the presence or application of contaminants but from the removal processes. Fiber bonding and strength can be restored to essentially their initial values in the aqueous PE removal and deinking processes. Both processes involved the use of sodium hydroxide — a swelling agent for cellulose fibers. The other removal processes did not restore the fiber properties and resulted in lower properties similar to those obtained with the recycled control.

Mohaupt and Koning (51) studied a method of recycling wax-treated corrugated. This involved feeding small pieces of the waxed board into a disc mill with 190°F water. All but 3% of the wax is removed in the process. The fiber stock was then washed with hot water and screened, reducing the wax content to less than 1%. The resulting fibers were made into medium, however the flat crush levels were low. It was suggested that the reclaimed fibers be blended with other fiber stock in order to produce medium with acceptable flat crush and edgewise compression.

Additional reviews of recycled fiber technology may be found in References (52-54).

UTILIZATION

The use of recycled fibers in kraft linerboard requires consideration of many technical factors. These mainly involve (a) the removal or dispersion of contaminants in the finish and (b) the proper processing of the fiber to obtain satisfactory quality levels. This study is directed toward the latter problem.

As mentioned previously, recycled fibers differ significantly from virgin fibers (and papers made therefrom) in many of these properties. Recycled fibers refined to the same freeness exhibit lower fiber strength and bonding potentials than the same fiber in the virgin state. The loss in bonding potentials appears to be most critical. In general, the properties of the paper which are mainly dependent on fiber bonding and strength decrease markedly with the number of times the fiber is recycled. Furthermore when the recycling is carried out at a given strength level — e.g., bursting strength — it has been noted that it is necessary to refine to progressively lower freeness on successive recyclings. Thus, in successive recyclings, the freeness, fiber length and associated sheet properties decrease and can reach impractical levels in terms of production rates. One of the primary differences between virgin and recycled fiber is related to the fact that the recycled fibers do not swell as readily in water and, hence, do not bond as well. These differences in bonding potential can be overcome, at least in part, by additional refining, by the use of chemical swelling and bonding agents, and by increased wet pressing.

The softwood kraft fibers in recycled old corrugated containers (OCC) have a greater strength potential in linerboard than the hardwood semichemical fibers. The latter are usually shorter in length and have a higher lignin and hemicellulose content than the softwood fibers. The semichemical hardwood fibers do not swell as readily in water on repulping. As a result, fractionation of the recycled OCC into long and short fiber fractions may lead to strength improvements because the two fractions could be treated or used separately. Selective treatment of the two fractions would be expected to be more effective than treatments of the OCC composite. These subjects are discussed in detail in the review of literature.

The above and other considerations provided the necessary background for conducting the survey of the technical state of the art with respect to the present usage of recycled fiber in linerboard.

For survey purposes fourteen plants and research groups were visited and numerous telephone interviews were made. The plant visits included the following:

1. Six mills producing linerboard with recycled fiber percentages ranging from about 8 to 35-40% dependent on grade weight and company policy.
2. Four mills producing linerboard from 100% recycled fiber. One of the four mills utilizes a Manchester former rather than a fourdrinier machine.
3. One mill producing recycled fiber medium only but which expects to produce 100% recycled fiber linerboard in the future.
4. One supplier of recycled fiber.
5. One research association active in this field and one research facility.

Present Usage of Recycled Fiber

Disregarding mills which reported usage of minor quantities of kraft clippings, a substantial number of mills employ mixtures of OCC and kraft clippings in appreciable quantities in their linerboard finish. In those mills blending recycled and virgin fiber, the amounts of recycled fiber used ranged from about 8 to 35-40% dependency on grade weight and company policy as shown in Table I.

TABLE I

AMOUNTS OF RECYCLED FIBER

Grade Weight, lb/M ft^2	Approximate Amounts of Recycled Fiber (OCC and Clippings), %
26-33	8-20[a]
38-42	13-40
69-90	14[b]-30

[a]One mill reported a short range target goal of 30%.
[b]Two mills reported that recycled fiber was generally used in only the 69-lb grade weight at an addition rate of about 14%.

In the lighter grade weights the amounts of recycled fiber used ranged from about 8-20% although one mill indicated their target goal is 30%. In their case severe appearance and slippery liner problems were being encountered as the ratio of OCC to clippings increased. For most of the plants visited it appeared that appearance requirements tended to limit the amounts employed in these grade weights.

In the 38-42-lb grade weights, present usages of recycled fiber as blends with virgin fiber ranged from about 13-40%. Target levels up to 40-50% were reported in one case. In the 69-90-lb grade weights present usages of recycled fiber as blends with virgin fiber ranged from about 14-30%.

The recycled fiber was placed in the primary furnish by all but one of the mills visited. The one mill blended the recycled fiber into both primary and secondary furnishes.

In general the recycled fiber furnish for the mills blending recycled and virgin fiber was made up of both old corrugated (OCC) and box plant clippings. Ratios of OCC to clippings varied over a wide range from mill-to-mill and from time-to-time. However, the higher users of recycled fiber tended to use OCC and clippings in ratios ranging from 50 to 85-90%. Difficulties with contaminants generally increased with the amount of OCC used, depending somewhat on the recycled fiber processing system. The usual problems encountered included appearance, build-up of petroleum base materials on felts, wire and driers and slippery liner. Most mills indicated that they could tolerate only small amounts of wax in the OCC supply. Reported upper limits on waxy contaminants ranged from about 1-3% although this is difficult to control. As previously mentioned, four of the mills visited produce 100% recycled fiber linerboard. All of these mills used OCC for the base sheet and a special furnish such as reject rolls and sack kraft clippings for the top sheet. In general the processing systems for the base sheet employed more cleaning and screening equipment than the mills using the lower amounts of recycled fiber.

One of the mills making 100% recycled fiber linerboard had a fractionating system for separating the OCC into long and short fiber fractions. The amount of "long fiber" obtained is usually in the 60-70% range. A Black-Clawson Cellusizer with 0.050-inch holes is employed, located after the hydrapulper. After fractionation, the long fiber fraction is screened and the accepts are thickened and stored in the decker chest for use in recycled linerboard. The grade weights made are 26, 33 and 42-lb linerboard. For linerboard they sometimes add pulp from purchased reject kraft rolls in a secondary former. Mottled white board is also made in this way. The short fiber fraction is employed in making 100% recycled fiber medium with a Concora specification of 60 lb.

Refining

Presently most mills blending virgin and recycled fiber stocks are refining a mixture of the two stocks. Disc mills operated at 3-4% consistency are commonly employed. The primary stocks are typically refined to Canadian Standard freeness values of 560-600 cc. In the case of the mills making 100% recycled fiber linerboard the primary stocks are typically refined to about 350-400 cc.

When blends of recycled and virgin fiber are refined together the recycled fibers are probably refined very little inasmuch as they are less responsive to the action of refiners than virgin fibers. Equivalent strength levels can be achieved with recycled fibers but they usually must be refined more to develop equivalent bonding (7,10). Because separate refining of the virgin and recycled fibers stocks should be more efficient, a number of companies were either considering this approach or in the process of installing equipment for it. In general, there was agreement that a study of refining should be part of the research program including study of separate refining. The general consensus appeared to be that the recycled fiber should receive a light "brushing" action with a minimum of cutting.

It was also mentioned that high consistency refining of recycled fiber stocks has been studied in mill trials. However, the mill trials failed to yield a significant improvement in board quality or productivity.

The possible use of the Frotapulper on recycled fiber stocks was also mentioned. This was developed in Europe for high consistency refining (at about 30% solids). It subjects the stock to a "kneading" action which is reported to have the advantage that contaminants are not reduced in size and, hence, can be screened out more readily after defibering and refining in the Frotapulper. A more complete description of the equipment and its performance is contained in the literature survey section of this report.

Chemical Additives

One of the primary differences between virgin and recycled kraft softwood fibers is the inability of the latter to swell readily in water and, hence, develop bonding in the final sheet. The deficiency in bonding can be overcome by additional refining, or by the use of chemical additives such as swelling agents or chemical bonding agents and by wet pressing.

The practical swelling agents are usually alkaline materials such as caustic soda. When OCC is treated with swelling agents such as caustic soda, higher strength levels are obtained (7,23), however the use of such agents would necessitate the use of an alkaline size. While swelling agents are not being presently used in treating OCC, it was generally agreed that the use of such agents should be studied. If successful, it would be possible to use white or green liquor for this purpose. One company cautioned, however, that pitch problems might be aggravated by the use of caustic treatments.

The application of bonding agents whether in the wet end or at the size press will usually permit attaining desired strength levels with less adverse effect on drainage than obtained by refining alone. Starches and gums are commonly used at present. The high users of recycled fiber find them essential in maintaining strength at reasonable drainage rate levels. It appears that when high amounts of recycled fiber are used, e.g., 100% recycled linerboard, bonding agents must be used to pick up 15-20 points of Mullen. Typically this is attained by the addition of cationic starch in the wet end and application of starch at the size press. The size press application was reported to add about 4-5 points Mullen. It is generally found that only the top side of the sheet can be treated in the size press because adhesion problems are encountered in the corrugating operation if the bottom side is treated. The bottom side is usually bonded to the medium on the corrugator and the starch size press treatment apparently makes the surface too nonreceptive to the corrugator adhesive to achieve good bonding. It also may be noted that drainage aids are usually employed at the higher levels of recycled fiber usage.

Thus, because of the need to obtain satisfactory quality levels without reducing drainage rates to uneconomical levels there is general agreement that the use of bonding and drainage aids are an important part of the research program.

The Institute is carrying out a funded research program directed to improved bonding of semichemical pulps. The strength of such pulps appears to be low because the lignin restricts swelling and provides greater fiber stiffness, which encourages weak interfiber bonding. If the ligneous fibers can be made to take up more water and swell more readily without sacrifice in yield, stronger and more versatile pulps could be produced. Thus, the study is directed to determining the effects of mild physical and chemical treatments on the swelling and stiffness of high yield pulp fibers, and to determine the effects of the more promising treatments on strength. The results of this study should have application to the short fiber fraction of OCC.

Asphalt Dispersion

There appears to be considerable controversy relative to the necessity for asphalt dispersion (A-D) equipment in the recycled fiber system. A number of systems are used both here and in Europe (43,57). In general, the basic principles are similar. The stock at about 30-35% consistency is heated to temperatures ranging up to about 300°F depending on the system. It is then passed to a dispersion unit where the contaminants are dispersed through the stock as a coating on the fibers. Natural asphalt generally has a melting point of about 280-290°F, hence it melts and disperses readily at the temperatures obtained in the process. However, it appears that higher melting synthetic plastic materials would not be as readily dispersed at the temperatures usually employed. In general, for asphalt-type contaminants, A-D units are effective in reducing or eliminating appearance problems in the final product and operational problems in the boardmaking process — e.g., pitch accumulations on wire or felt. However, Kenworthy notes that fiber quality is degraded (43). He attributes this loss in fiber quality to high temperature effects, the mechanical actions of the disperser and to losses in bonding potential due to "coating" of the fibers by the dispersed contaminants. The energy costs may also be a disadvantage inasmuch as steam costs are estimated to be about 1700 lb per ton (57).

The above advantages or disadvantages were cited by various companies visited in the survey. Some of the companies believe that A-D units are necessary to cope with the contaminants that are not removed by screening or cleaning; other companies believe that proper cleaning and screening remove a sufficient amount of the objectionable contaminants as to make A-D systems unnecessary. The possible adverse effects of dispersion on bursting strength were cited by other companies as an objection to A-D. On the other hand, A-D systems provide conditions of relatively high temperature and pressure as well as reaction time. Thus, it is possible that the addition of chemical agents in the A-D system may be one way to improve quality.

Presently four of the mills visited during the survey are operating A-D units and a fifth mill is considering adding a unit to its system. Most of these mills used large amounts of recycled fiber either in linerboard or medium.

Fractionation

OCC is composed of two primary fibrous components, namely, kraft linerboard and corrugating medium. With suitable screens the OCC can be separated into long and short fiber fractions. The long fiber fraction will contain mainly unbleached softwood kraft fibers which have reasonably good strength potentials. The short fiber fraction will consist to a large extent of high yield hardwood semichemical fibers. Because of the differences in fiber specie, degree of delignification, etc., the two fractions will react differently to various mechanical and/or chemical treatments. Therefore, fractionation provides the opportunity to treat each fraction differently. This portion of the study was believed to be important by a number of the companies surveyed.

As discussed in the literature survey, several methods for separating OCC into long and short fiber fractions have been reported (19-23). However, the only domestic commercial systems in operation have been based on the use of pressure screens. In one installation, a Black-Clawson Cellusizer with 0.050-inch holes is employed after the hydrapulper to separate the stock into two fractions. The long fiber fraction comprises about 60-70% of the total stock and is employed in making recycled linerboard. The short fiber fraction is used to manufacture medium. As mentioned in the literature survey, The Mead Corporation (24) successfully operated two mills in a similar fashion for some time. In another operation, the short fiber fraction is used in the center plies of a combination boxboard while the long fiber is used in recycled linerboard. Thus, fractionation appears to be technically feasible.

RECYCLED FIBER PROCESSING SYSTEMS

Contaminants affect the production of linerboard in many ways. They adversely affect the appearance of the sheet and cause difficulties in the forming, pressing and drying due to plugged wires and felts, "coated" press rolls and drier drums. In addition, they may have an adverse effect on the quality of linerboard in terms of lower strength.

In general, the secondary fiber processing system must remove or render innocuous enough of the contaminants in the incoming stock to permit use of the fibers in the economic manufacture of linerboard. As Mugg (55) has noted, the problems encountered in most mills have increased in recent years. The recent publication "Paper Recycling — The Impact of Contaminants 1973-1985" (56) gives an overview of problems due to contaminants. In the report, it is noted that the particularly troublesome contaminants in recycled fiber come primarily from the newer synthetic adhesives and coatings. These include hot melt and pressure sensitive adhesives, polystyrene foams and synthetic or natural fibers. In the case of OCC, paraffin waxes and polyethylene materials are frequently encountered. Most mills visited during the survey indicated they could tolerate only small amounts of such materials in the incoming stock — preferably less than 1-3%.

Recycled fiber systems for OCC generally include equipment for pulping, cleaning, screening and, in some cases, asphalt dispersion equipment. As mentioned, 11 operating systems were visited during the course of the survey. While the system had certain similarities, there were considerable differences from mill-to-mill in types of equipment and their arrangement in the process. Thus, the systems described in the following are illustrative of the processes used but not necessarily typical to a given mill.

Figure 4 is a simplified schematic diagram of the recycled fiber system for a mill using moderate amounts of recycled fiber as a blend with virgin fiber. Figure 5 shows a simplified diagram of the recycled fiber system for the base sheet furnish for a high user of recycled fiber. As may be noted, the user of higher percentages of recycled fiber has much more cleaning and screening equipment than the system in Fig. 4. The primary system for the high user of recycled fiber includes a rough cleaner, pressure screen, core extraction centrifugal cleaners and a side hill screen. The core extraction centrifugal cleaners (Bird Triclean) make it possible to extract some of the low density materials at the vortex of the cleaner. In contrast, the system in Fig. 4 includes only a rough cleaner and pressure screen. However, it also includes a "Flote-Purge" system in the hydrapulper in order to keep the hydrapulper essentially free from an accumulation of unpulped materials not removed by the ragger and junker. In this case, the 1/4 inch extraction holes were located over a 300° sector; the remaining 60° sector had 1 inch holes. [Note: The Flote-Purge system is discussed by Root (57).]

The secondary cleaning stages in Fig. 4 and 5 also differ. In Fig. 4, the rejects from the primary screens are given a secondary screening. The accepts from the secondary screen go to the thickeners while the rejects are further screened and then processed through Bio-Z cleaners. These units employ flotation to strip thermoplastic materials from the pulp (55). An extensive discussion of the effectiveness of such units has recently been published by Zemanek (58).

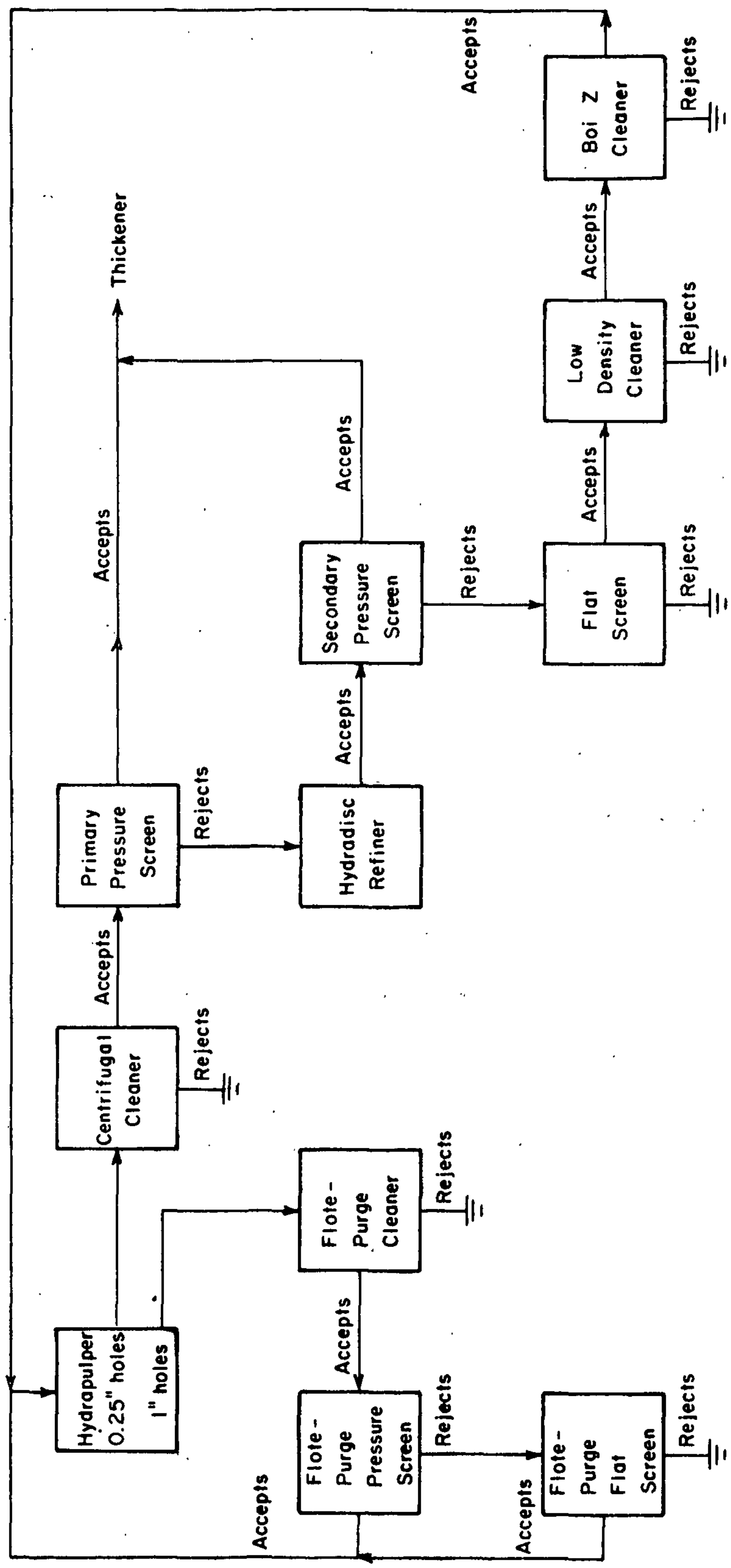


Figure 4. Recycled Fiber Process System for Use of Recycled Fiber as Supplemental Furnish

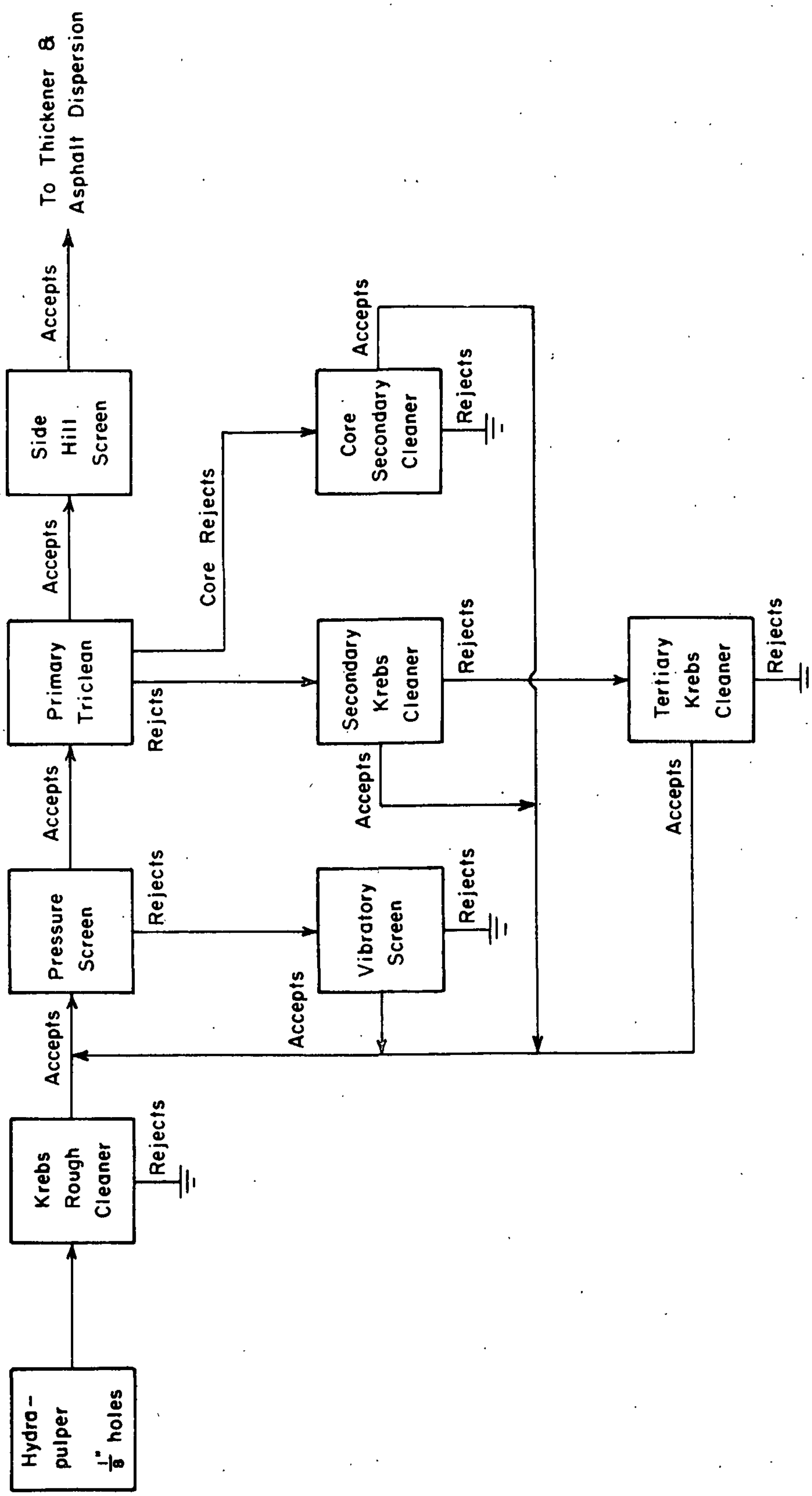


Figure 5. Recycled Fiber Process System for Use in Recycled Fiber Linerboard

In Fig. 5 the rejects from the primary screens are deflaked and then screened in vibratory screens with 0.125-inch diameter holes. The accepts from the vibratory screens are returned to the primary screen. The rejects from the primary Tricleans are given a secondary cleaning in Krebs cleaners in two or three stages and the accepts are also returned to the stock chest before the primary screens. Finally the core bleeds from the primary Tricleans which are rich in hot melts and latex particles are cleaned with core extraction centrifugal cleaners.

The extraction holes in the hydrapulpers generally ranged between 1/8 inch and 5/16 inch for most of the mills visited. However, in two of the mills visited, the recycled fiber systems were designed more in line with the European practice of using larger holes in the hydrapulper extraction plates so as to avoid grinding up the contaminants into very small pieces. In these two cases, a Voith Turboseparator was employed after the hydrapulper. The Turboseparator has the capacity of removing both low density and high density contaminants, and at the same time defibers the stock. The low density contaminants are collected in the vortex and extracted through a central valve; the high density contaminants collect in a tangential trap. A short description of the Turboseparator may be found in Reference (55) along with a description of the Beloit-Jones Bel-Cor which accomplishes a similar function.

Figure 6 shows a simplified flow diagram which is illustrative of a recycled fiber system which follows the European approach to cleaning and screening. In the primary stage this system employs a mid-consistency cleaner followed by Finckh screens and Boi-Z cleaners — the latter to remove low density contaminants (55). In the secondary stage, the rejects from the primary Finckh screens and Boi-Z cleaners are subjected to further cleaning and screening in Finckh screens, Boi-Z and Voith Morton No. 200E cleaners. The accepts from these operations are eventually sent back to the mid-consistency cleaners in the primary stage.

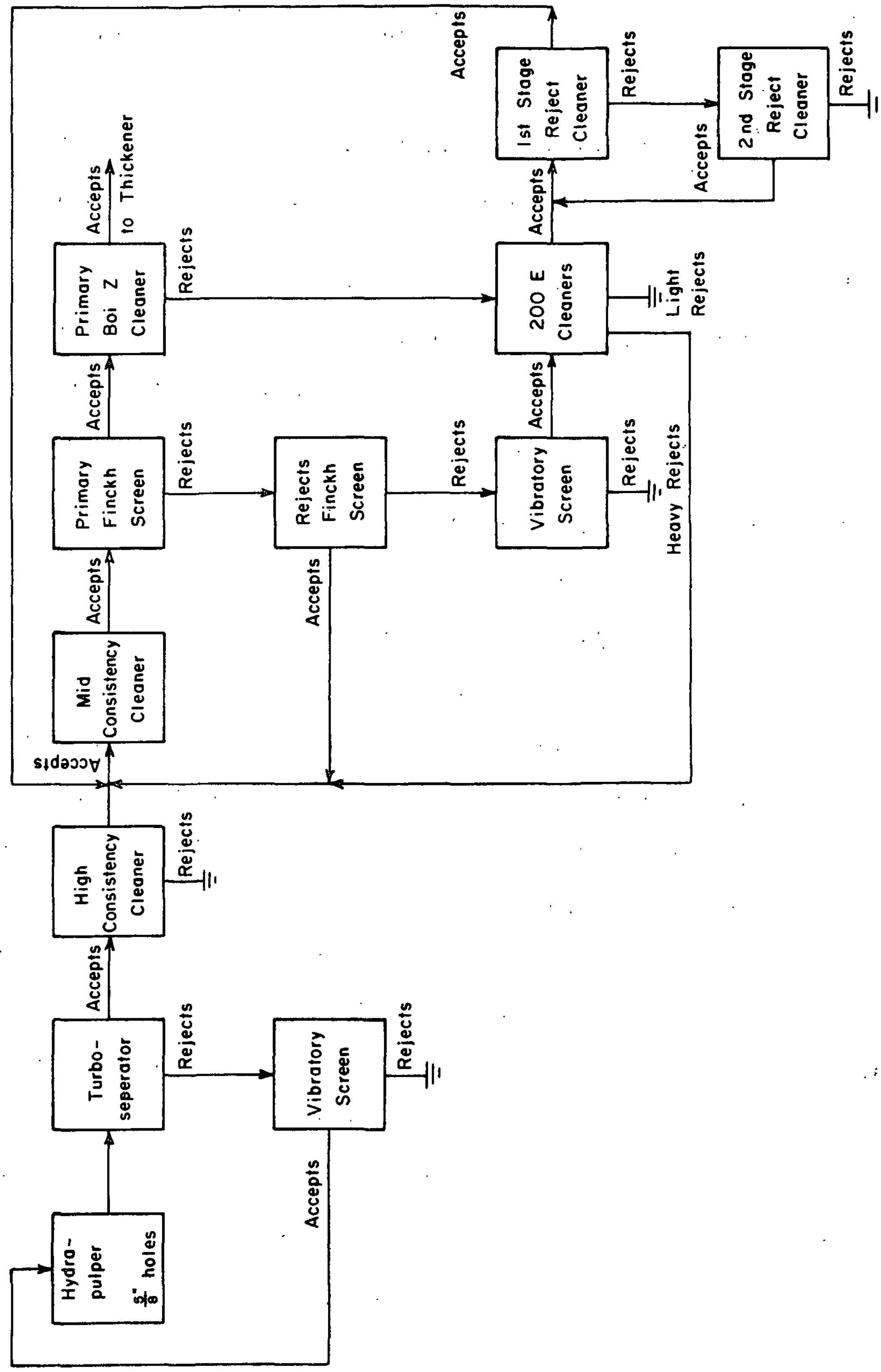


Figure 6. Recycled Fiber Process System Following "European" Practice

In general, for the mills visited, hydrapulper temperatures ranged between about 110°F and 125°F, although one operation employed a 170°F temperature. A number of mill people reported that higher temperatures cause more difficulties with wax contaminants. As mentioned previously, most mills report difficulties with wax contaminants and try to hold the amount of wax in the incoming furnish below 1-3%.

Some mills reported severe problems with petroleum base contaminants building up in the driers, third press and lump breakers. It was believed that the problem could be controlled or eliminated by installing a more complete screening system on the primary screen rejects.

Slippery liner problems have been encountered by many mills using recycled fiber. These are usually attributed to small amounts of waxy materials in the furnish and system. Chase (10) has described the relation of low slide angles to traces of wax in the white water system and indicates such agents as colloidal silica or alumina can be used to increase the slide angle to acceptable levels. As a part of this study, board samples exhibiting "low" and "acceptable" slide angles were analyzed for extractives. The "low" slide angle samples contained slightly greater amounts of waxy materials in the extractives than the board with acceptable friction levels. While the differences were not large, even small amounts of such materials can have a marked effect on friction characteristics. This is illustrated by the fact that application of paraffin waxes to corrugating medium in amounts of about 10 lb/$\overline{MM}$ ft^2 is sufficient to permit "cold" corrugating at commercial speeds. The application of such agents has been shown to reduce the kinetic coefficient of friction of medium to a steel surface from about 0.55 to 0.12 (59).

As mentioned previously the need for asphalt dispersion equipment in the processing of recycled fiber was controversial. Four of the eleven companies visited in this survey had asphalt dispersion systems. It appeared that most of the high users of recycled fiber had dispersion systems. Most of the companies not having dispersion systems believed they were not necessary because most, if not all, contaminants can be removed by screening. The possible adverse effects of asphalt dispersion treatment on bursting strength was also cited as an objection to their use, as discussed in the literature review.

One of the companies surveyed was manufacturing acceptable liner and medium by the fiber fractionation method from 100% recycled fiber. The "long" fiber fraction is employed in the manufacture of linerboard and the "short" fiber fraction in medium. For linerboard they sometimes add pulp from purchased reject kraft rolls on a secondary former. The separation into fractions is done in a Black-Clawson Cellusizer with 0.050-inch holes. The ratio of long to short fiber is in the 60-70% range. The liner and medium recycling systems are outlined below.

Liner System

1. Hydrapulper with ragger and junker. The extraction hole size is 3/8 inch. The hydrapulper temperature is maintained at 70-80°F to prevent plastic materials from softening and the pH is kept at about 7.0.
2. Cellusizer with 0.050-inch holes. Long fiber to liner, short fiber to medium.
3. P 36 screen with 0.090-inch holes. Rejects back to pulper.
4. Accepts to PS 24 screen with 0.022-inch slots.
5. Accepts from PS 24 screen to decker.
6. Consistency adjusted to 2% before Bird Centriscreen.
7. Bauer cleaners.

8. Machine screens.

9. Refining with 1 Claflin and 1 Jordan to a freeness of 350 cc CSF.

Medium Recycling System

1. Hydrapulper (see liner system).

2. Cellusizer (see liner system).

3. Decker.

4. Machine chest.

5. Refining (1 Claflin and 1 Jordan) to a freeness of 310 cc CSF.

6. Bauer cleaner.

7. Machine chest.

QUALITY COMPARISONS

During the survey, samples of linerboard made with various amounts of recycled fiber were obtained from various mills. These samples were evaluated in terms of the following properties: basis weight, caliper, edgewise compression strength (regular and modified ring), bursting strength, tension properties and tearing strength (42-lb grade weight).

While samples having recycled fiber contents ranging up to 100% were obtained, it should be kept in mind that each sample came from a different mill. Therefore, differences in properties between samples may be expected to reflect mill-to-mill practices in pulping, processing and paper machine operation in addition to recycled fiber content. Also, only a limited number of samples were obtained and the individual samples may not be entirely representative of the particular mill quality levels. For such reasons the results must be interpreted with caution.

With the above in mind, the results obtained on 42-lb linerboard samples are tabulated on Tables II and III. Figure 7 shows the bursting strength results in relation to recycled fiber content. The February 1977 FKBG cumulative average from the linerboard base-line study (Project 2694-1, Report Sixty-one, April 27, 1977) is also shown in the figure for reference purposes. Most of the samples exhibited lower bursting strength than the FKBG average; however, this may represent mill operational practice and philosophy as much as recycled fiber content as witness the fact that one of the "virgin" kraft linerboard samples had a bursting strength of 100 psig. The samples having recycled fiber contents in 20-30% range exhibited bursting strengths of about 100 psig and the two 100% recycled fiber linerboards had bursting strengths of 94 and 102 psig, respectively. Thus, it appears that commercial bursting strength levels are achieved over a wide range of recycled fiber content. This would be expected if appropriate processing (refining, additives, wet pressing, etc.) of the fiber furnish is employed.

Past theoretical and experimental studies have indicated that in top load box compression the box panel walls behave as thin plates (60). As discussed in Ref. (60), the cross direction (CD) edgewise compression strength and flexural stiffnesses of combined board are the properties which govern top load box compression strength. The dominant property is the CD edgewise compression strength of the combined board which is dependent on the CD edgewise compression strengths of the components — i.e., linerboard and medium. With this in mind, the modified ring compression results on 42-lb linerboard are shown in Fig. 8. The CD modified ring strengths show no discernible relation to recycled fiber content and the samples with various amounts of recycled fiber exhibited strengths which were comparable to the "virgin" kraft samples. Similar results were obtained for the machine direction modified ring compression strengths.

TABLE II

WEIGHT, BURSTING STRENGTH AND EDGEWISE COMPRESSION RESULTS ON 42-LB LINERBOARD

Code	Approximate Recycled Fiber Content, %	Basis Weight, lb/M ft^2	Caliper, pt	Apparent Density, lb/pt	Bursting Strength, psig	Regular Ring Compression, lb/in.		Modified Ring Compression, lb/in.	
						MD	CD	MD	CD
A	Virgin[a]	40.8	11.9	3.4	100	19.7	14.7	21.0	16.5
B	Virgin[a]	40.5	13.3	3.0	107	16.8	12.8	19.3	14.8
C	5	42.9	12.6	3.4	94	15.5	10.7	20.0	13.8
D	13	43.3	11.8	3.7	117	19.7	14.7	21.5	17.5
E	20	40.9	11.2	3.6	101	17.2	12.3	19.3	14.7
F	24	43.0	12.5	3.4	99	18.5	13.3	20.3	16.0
G	25	42.4	13.0	3.3	100	15.0	12.0	18.0	14.0
H	30	43.9	13.6	3.2	101	18.5	11.2	21.0	14.5
I	100	43.6	14.8	3.0	94	19.3	14.8	20.0	14.5
J	100	43.0	15.3	2.8	102	22.7	16.8	25.0	19.2

[a]Manufactured from essentially 100% virgin kraft pulp.

TABLE III

TENSILE AND TEARING STRENGTH PROPERTIES OF 42-LB LINERBOARD

Code	Approximate Recycled Fiber Content, %	Tensile Strength, lb/in.		Stretch, %		Tensile Stiffness (Et), lb/in.		Tensile Energy Absorption, ft·lb/ft^2		Elmendorf Tear, g	
		MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
A	Virgin[a]	95.6	31.6	1.52	3.95	9,370	3,050	10.9	11.2	274	336
B	Virgin[a]	81.9	32.9	1.23	2.57	9,480	3,280	7.3	7.2	325	363
C	5	79.2	36.3	1.33	4.12	9,050	2,960	8.1	13.1	349	352
D	13	91.9	36.4	1.92	3.08	9,120	3,790	13.5	9.8	294	342
E	20	81.8	32.5	1.82	3.56	8,580	3,260	11.8	10.3	266	342
F	24	81.1	34.1	1.67	4.43	9,030	3,260	10.6	13.4	309	357
G	25	79.5	34.2	1.34	3.40	8,880	3,220	7.8	10.0	315	332
H	30	95.7	30.6	1.32	3.64	11,000	5,640	9.4	9.8	254	320
I	100	80.5	34.6	1.66	3.63	8,810	3,630	10.2	11.4	263	294
J	100	83.4	36.0	2.00	4.10	8,620	3,670	12.6	13.4	258	258

[a]Manufactured from essentially 100% virgin kraft pulp.

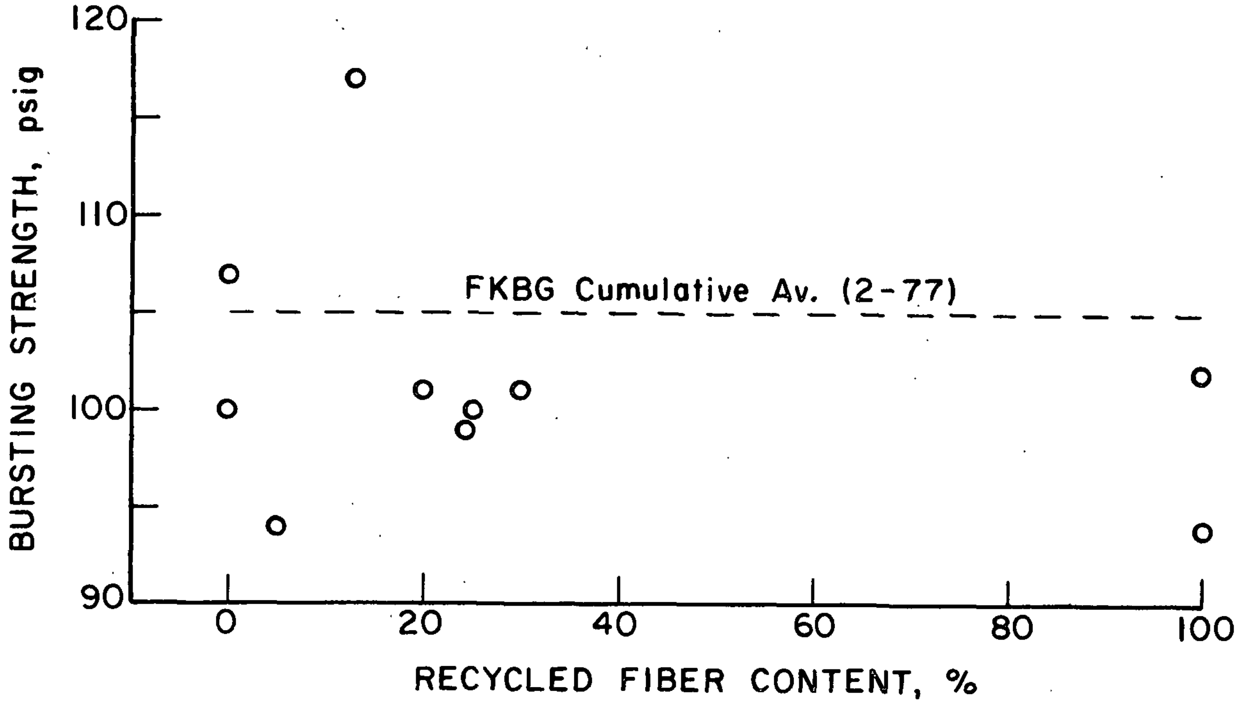


Figure 7. Bursting Strength Results on 42-lb Linerboard

The tensile strength and stiffness (Et = tensile modulus × thickness) results on the 42-lb linerboard samples are illustrated in Fig. 9 and 10, respectively. In general, while the samples exhibited considerable variation in strength and stiffness, the variations did not appear to be related to recycled fiber content. The tensile stiffness of the liners is the main property affecting the flexural stiffness of combined board (aside from flute geometry). Thus, these results suggest that the flexural stiffnesses of combined boards made from linerboards with various amounts of recycled fiber content should be comparable to the stiffnesses obtained with "virgin" kraft linerboard, assuming appropriate processing.

Based on the above, it appears that linerboards made with substantial amounts of recycled fiber up to 100% can exhibit satisfactory commercial levels

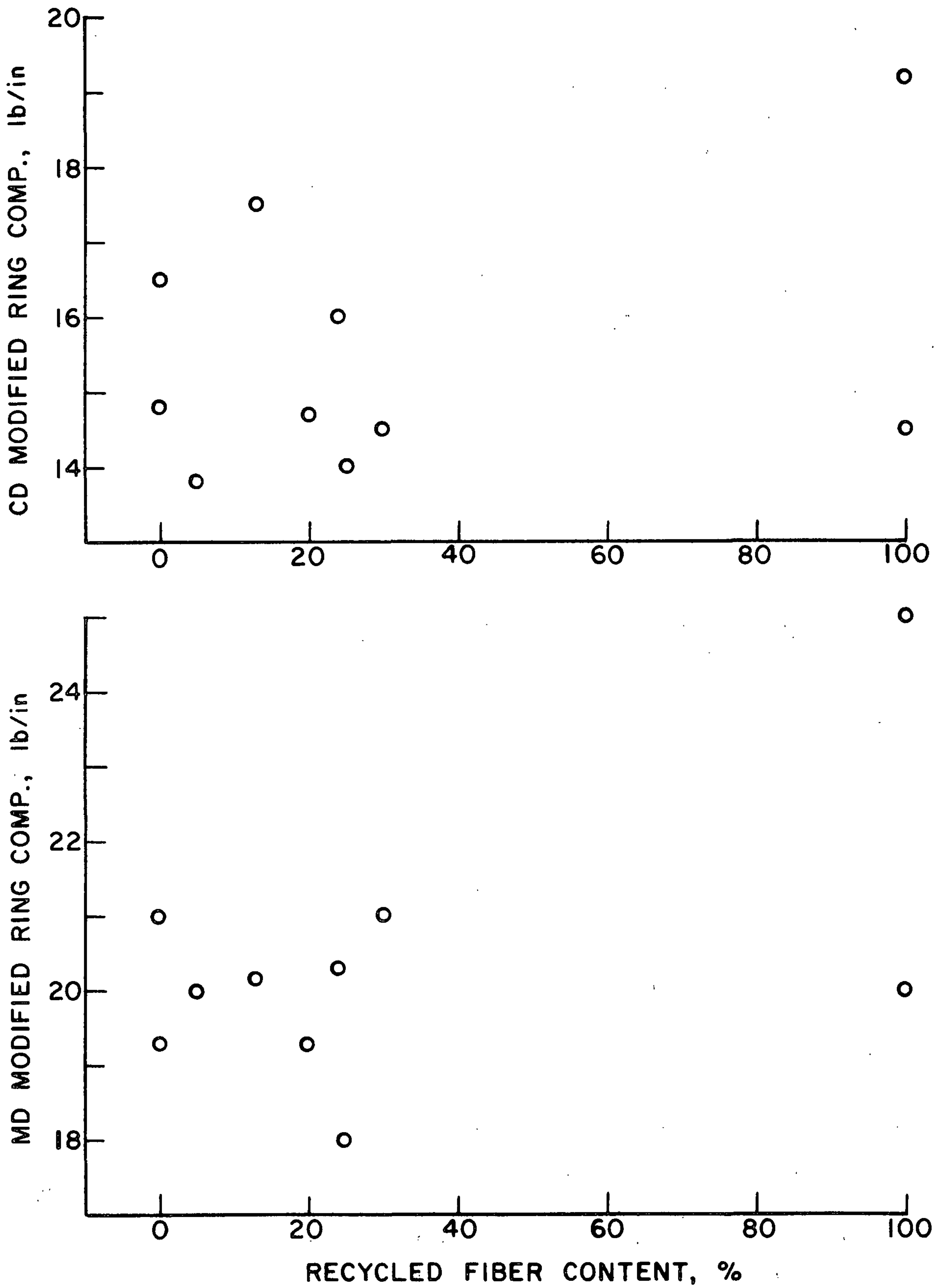


Figure 8. Ring Compression Results on 42-lb Linerboard

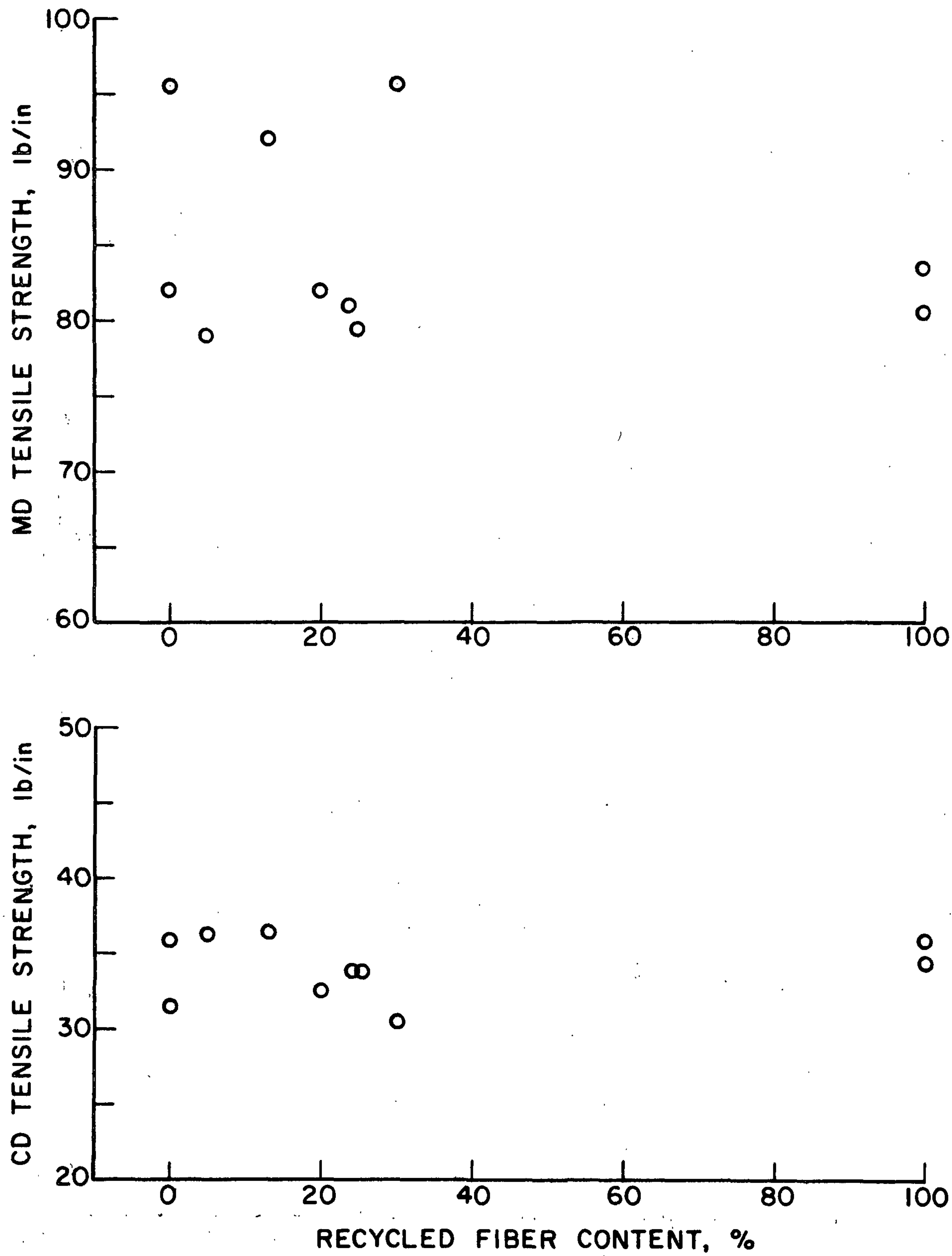


Figure 9. Tensile Strength Results on 42-lb Linerboard

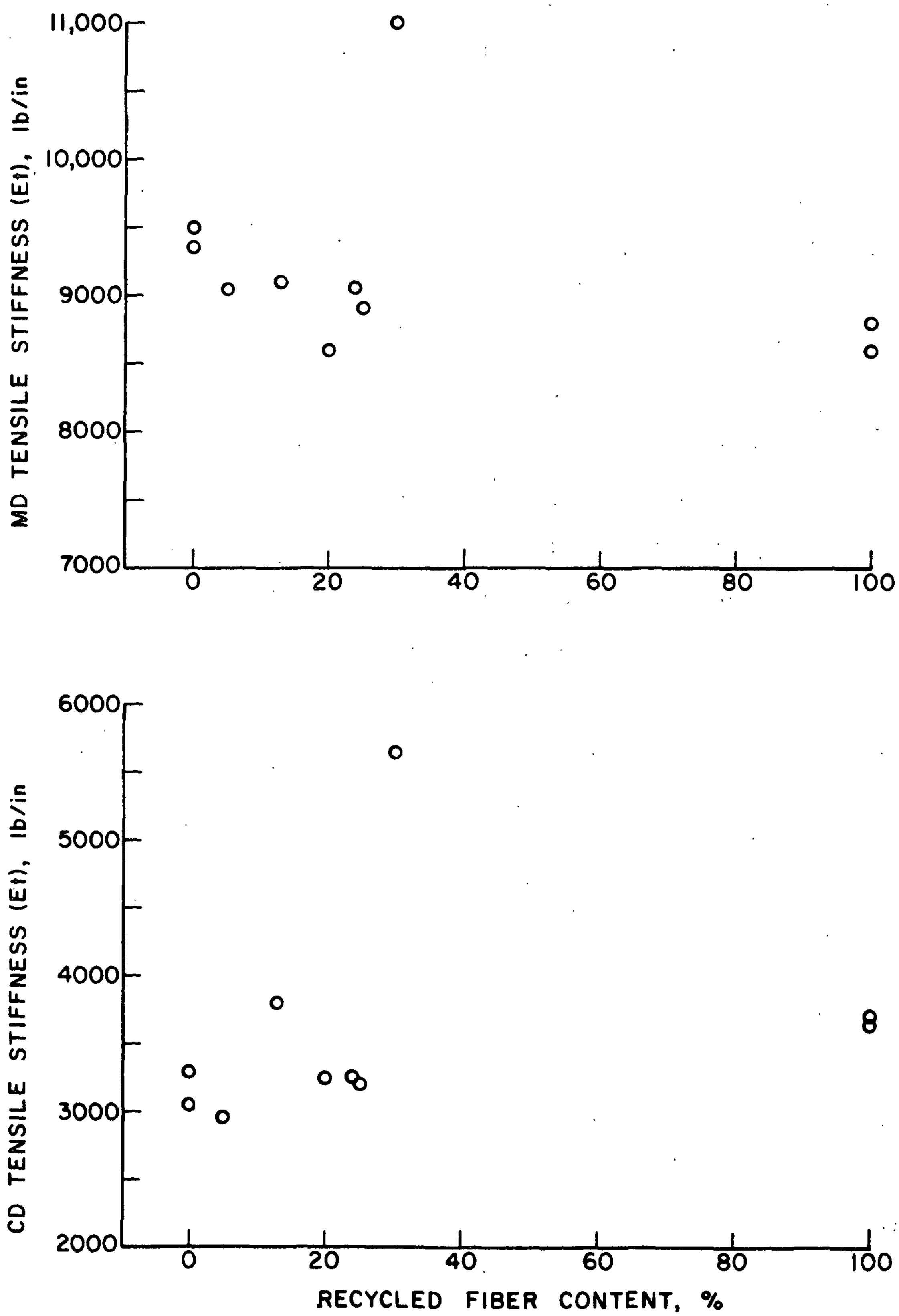


Figure 10. Tensile Stiffness (Et) on 42-lb Linerboard

of both edgewise compression strength and tensile stiffness. Thus the top load box compression strengths of boxes made with such linerboards may attain commercial quality levels.

Figures 11 and 12 show the tearing strengths results obtained on the 42-lb linerboards in the MD and CD directions, respectively. In general, the linerboard samples having recycled fiber contents up to 30% exhibited variations in tearing strength which were not clearly related to recycled fiber content. There did appear to be some tendency for the 100% recycled linerboards to exhibit lower tearing strengths than the other sample — particularly in the cross direction. This might be expected based on the work by McKee (5), Horn (7) and others (8,9). This may result in lower rough handling box performance due to score-line tearing although it should be noted that the tensile energy absorption characteristics of the 100% recycled linerboard were comparable to the other samples (see Table III). Koning and Godshall (9) reported losses in impact performance ranging from 9-17% using refined 100% recycled linerboards.

Linerboard samples were also obtained in the 26, 33, 38 and 69-lb grade weights. In general, fewer samples were obtained in these grade weights and extra caution is required in interpreting the results.

The results obtained in the 26 and 33-lb grade weight samples are shown in Tables IV and V. Keeping in mind the limited number of samples and mill process variations, the bursting strengths of the linerboard with recycled fiber were generally lower than the FKBG base-line averages of 71 and 86 psig for the 26 and 33-lb grade weights (see Fig. 13). In terms of edgewise compression strength there was considerable variation from sample to sample but there was no clear evidence that the differences between samples were due to recycled fiber content (see

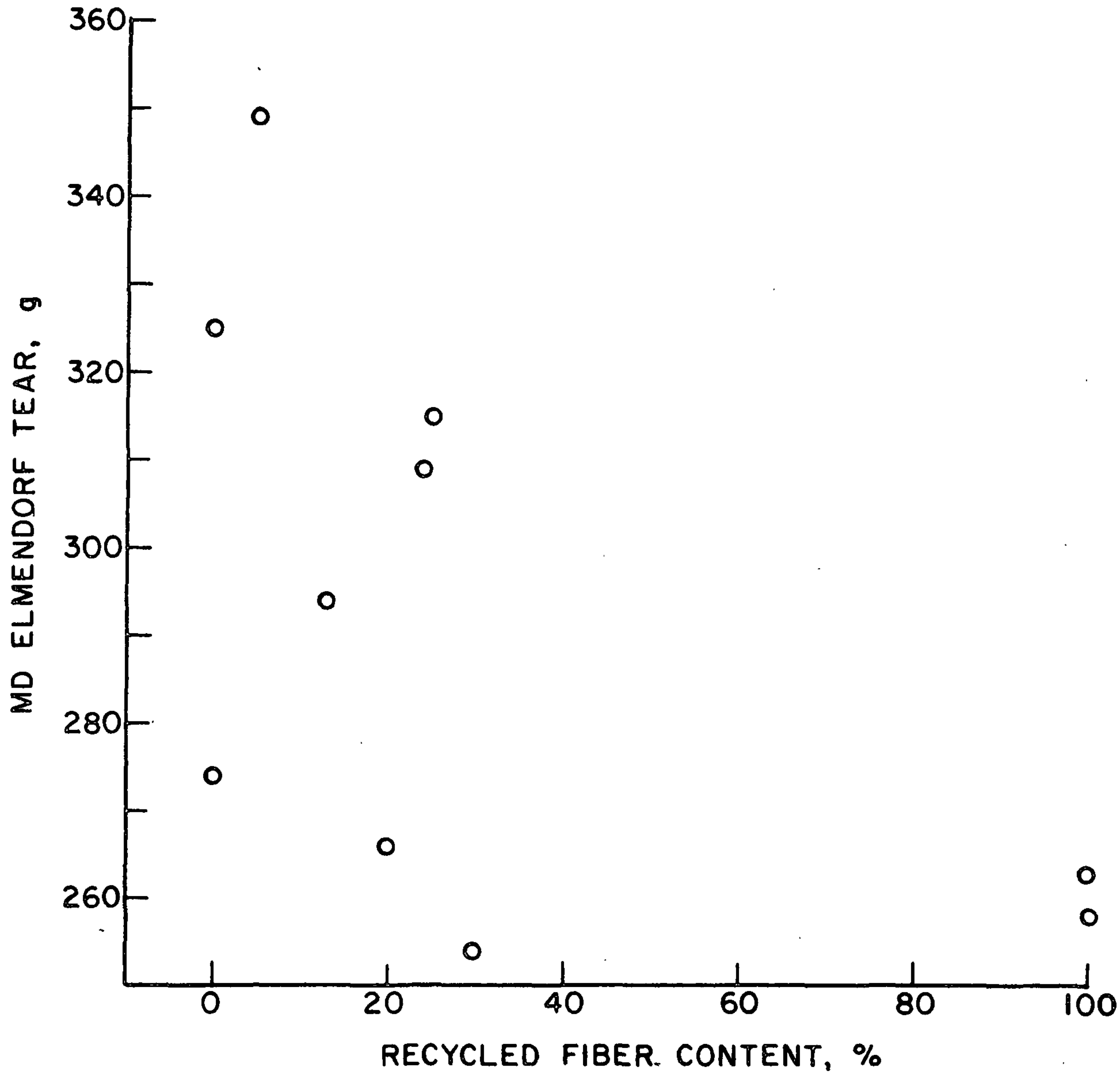


Figure 11. Machine Direction Tearing Strength Results on 42-lb Linerboard

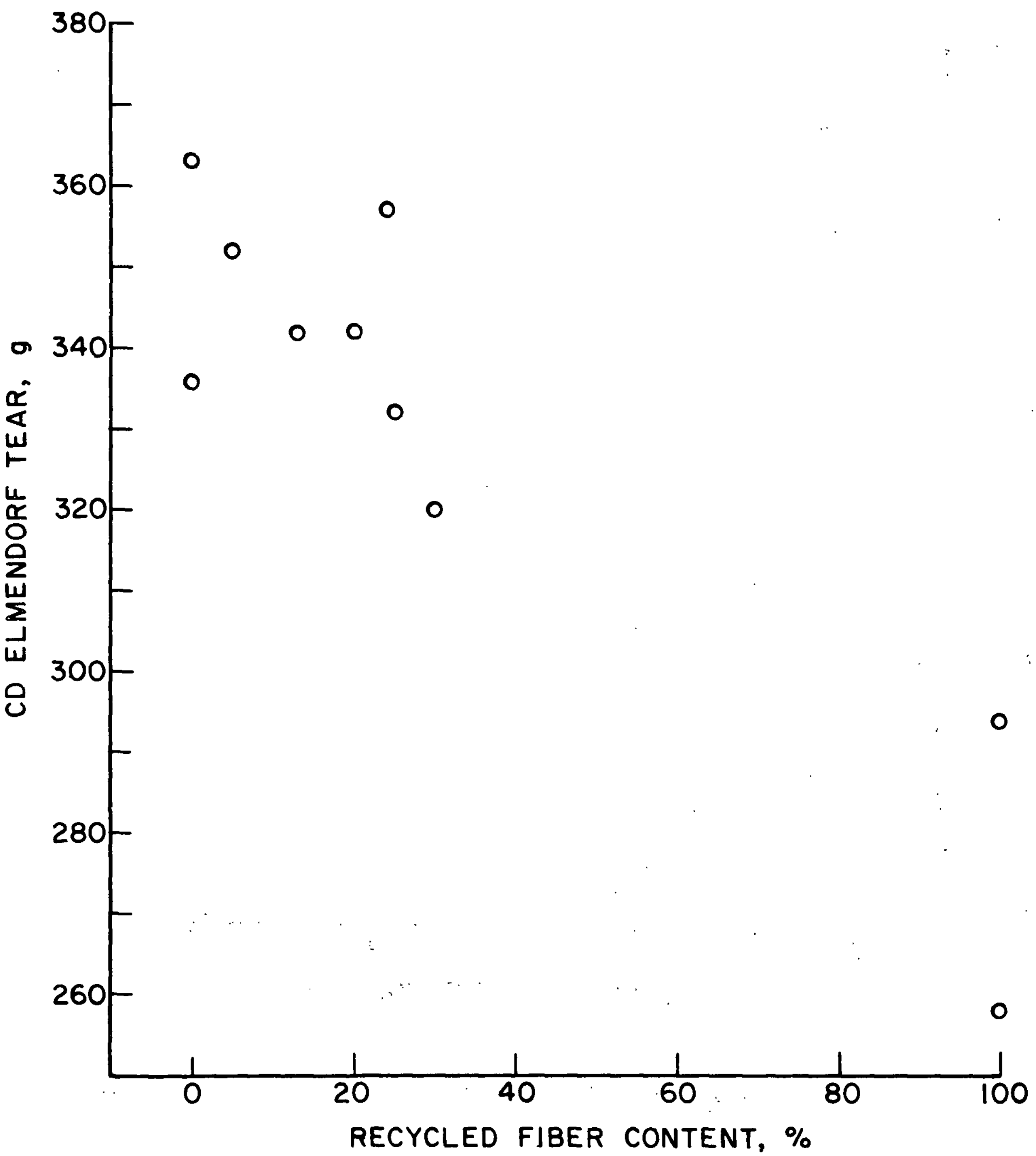


Figure 12. Cross Direction Tearing Strength on 42-lb Linerboard

TABLE IV

WEIGHT, BURSTING STRENGTH AND EDGEWISE COMPRESSION STRENGTH ON 26- AND 33-LB LINERBOARD

Code	Approximate Recycled Fiber Content, %	Basis Weight, lb/M ft^2	Caliper, pt	Apparent Density, lb/pt	Bursting Strength,[a] psig	Regular Ring Compression, lb/in. MD	Regular Ring Compression, lb/in. CD	Modified Ring Compression, lb/in. MD	Modified Ring Compression, lb/in. CD
				26-lb Linerboard					
A	Virgin[b]	26.3	9.2	2.9	74	11.0	7.2	15.5	10.5
B	Virgin[b]	27.3	8.9	3.1	77	10.8	8.2	15.5	10.5
C	15	26.8	8.2	3.3	61	8.7	6.2	13.0	10.0
G	18	25.3	7.8	3.2	63	8.0	4.8	15.0	10.5
H	30	26.4	8.5	3.1	61	8.8	6.5	13.5	9.5
I	100	27.1	8.7	3.1	63	8.5	5.7	14.5	10.5
J	100	27.7	9.8	2.8	69	9.8	6.0	18.0	12.0
				33-lb Linerboard					
A	Virgin[b]	32.1	10.6	3.0	83	13.7	9.7	19.0	12.5
B	Virgin[b]	33.0	10.2	3.2	101	14.7	9.5	20.0	13.0
C	6	33.1	10.1	3.3	76	12.3	7.8	19.0	12.5
D	7	33.9	10.1	3.4	100	16.5	12.3	23.0	17.0
G	15	32.3	10.0	3.2	69	11.7	9.0	17.0	12.0
H	30	33.7	10.6	3.2	79	12.3	8.5	18.5	10.5
I	100	35.4	10.9	3.2	79	13.8	11.0	20.0	14.5
J	100	33.8	11.3	3.0	78	13.3	9.3	21.0	14.5

[a]FKBG liner base-line averages were 71 and 86 psi for 26- and 33-lb linerboards (Project 2694-1, Report Sixty-one, April 27, 1977).

[b]Manufactured from essentially 100% virgin kraft pulp.

TABLE V

TENSILE PROPERTIES OF 26- AND 33-LB LINERBOARDS

Code	Approximate Recycled Fiber Content, %	Tensile Strength, lb/in.		Stretch, %		Tensile Stiffness (Et), lb/in.		Tensile Energy Absorption, ft lb/ft^2	
		MD	CD	MD	CD	MD	CD	MD	CD
				26-lb Linerboard					
A	Virgin[a]	67.0	21.5	1.61	4.63	7,110	2,070	8.2	9.0
B	Virgin[a]	63.3	25.3	1.17	2.50	7,660	2,680	5.5	5.3
C	15	49.5	24.6	1.32	4.51	5,670	2,100	5.0	9.6
G	18	52.4	20.1	1.34	6.54	6,060	1,490	5.2	12.0
H	30	51.8	22.0	1.44	3.67	5,590	2,050	5.6	7.2
I	100	50.7	16.1	1.79	4.68	5,680	1,610	7.0	7.1
J	100	60.8	18.8	1.74	5.81	6,290	1,670	8.0	10.3
				33-lb Linerboard					
A	Virgin[a]	73.2	24.6	1.54	4.18	7,690	2,420	8.5	9.3
B	Virgin[a]	78.9	30.1	1.13	3.04	9,450	2,960	6.9	7.8
C	6	68.9	23.7	1.35	5.56	7,760	1,790	7.2	12.4
D	7	78.4	35.8	1.81	4.28	7,760	3,350	10.8	13.6
G	15	52.2	25.6	1.31	3.34	6,530	2,350	5.2	7.4
H	30	68.0	25.3	1.62	3.33	7,100	2,430	8.4	7.4
I	100	65.1	27.7	1.90	3.31	7,000	3,020	9.6	8.3
J	100	66.9	24.2	1.64	4.62	7,330	2,340	8.4	10.1

[a]Manufactured from essentially 100% virgin kraft pulp.

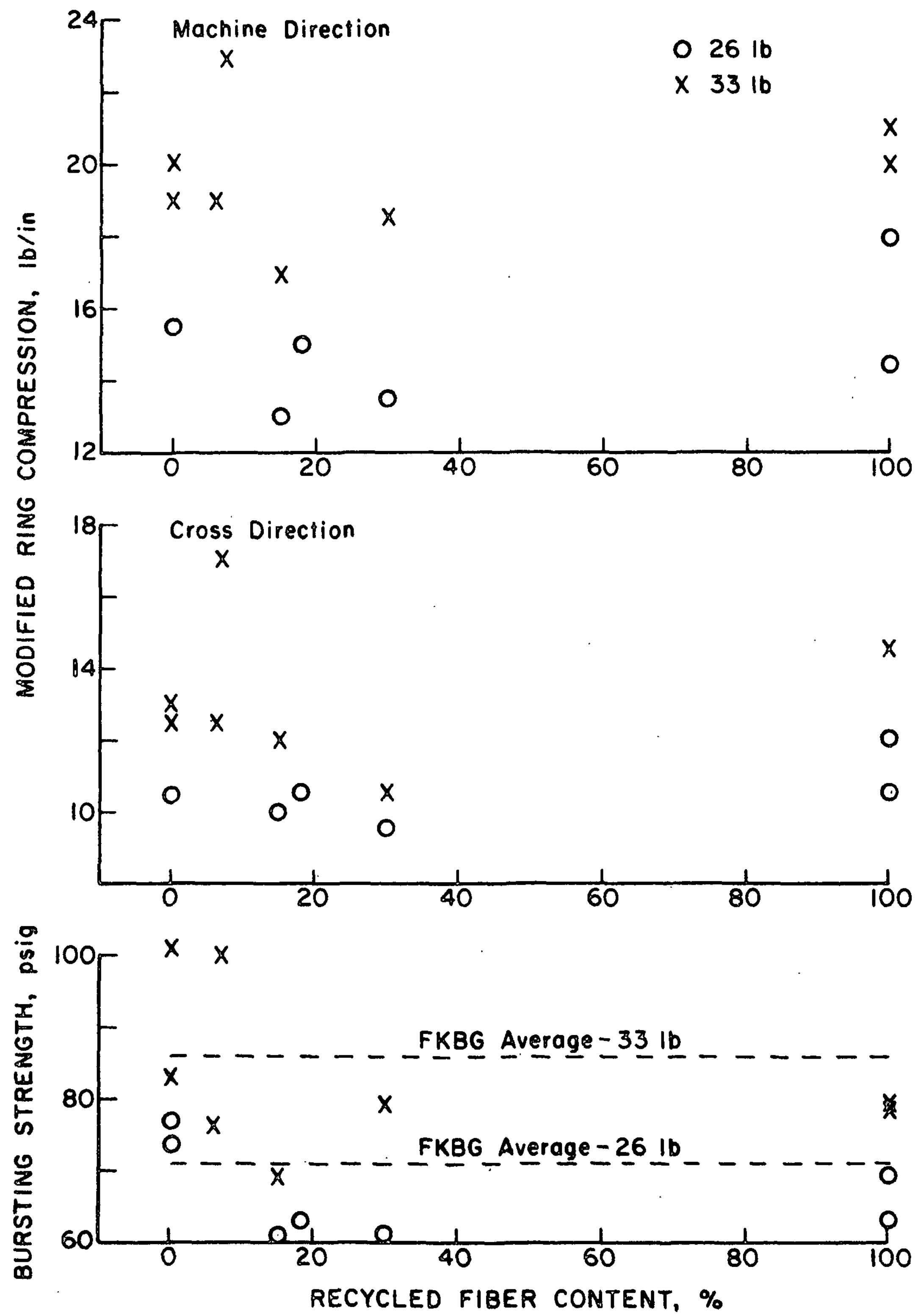


Figure 13. Bursting Strength and Edgewise Compression Results on 26 and 33-lb Linerboards

Fig 13). In general, the edgewise compressions of the boards made with various amounts of recycled fiber were approximately comparable to the strengths exhibited by the "virgin" kraft linerboards.

In Table V the 26-lb linerboards made with recycled fiber tended to exhibit somewhat lower machine direction tensile strengths and stiffnesses (Et) than the two virgin kraft samples. The cross direction tensile strengths and stiffnesses of the boards made with 100% recycled fiber were also somewhat lower than the results for the two virgin kraft linerboards. For the 33-lb grade weight there appeared to be no clear relation between recycled fiber content and either tensile strength or stiffness.

The results obtained on the 38 and 69-lb grade weight samples are tabulated in Tables VI and VII. Referring to Table VI and Fig. 14, it appears that the bursting strength and edgewise compression strength results on the 38-lb samples containing recycled fiber were generally comparable to those obtained in the virgin kraft linerboards. The same is held true in the case of the bursting strength results on the 69-lb linerboards which had a maximum recycled fiber content of 30%.

The edgewise compression results on the 38-lb liners are also shown in Fig. 14. As in the case of the other grade weight samples, there appears to be no discernible relation between recycled fiber content and either MD or CD edgewise compression strength. In general, the compression results obtained on the 69-lb linerboard in Table VI also show no marked tendency to vary with recycled fiber content.

The tensile strength and stiffness (Et) of the 38 and 69-lb linerboard samples made with recycled fiber are approximately comparable to the results for the two virgin kraft samples.

TABLE VI

WEIGHT, BURSTING STRENGTH AND EDGEWISE COMPRESSION RESULTS ON 38- AND 69-LB LINERBOARDS

Code	Approximate Recycled Fiber Content, %	Basis Weight, lb/M ft^2	Caliper, pt	Apparent Density, lb/pt	Bursting Strength,[a] psig	Regular Ring Compression lb/in. MD	Regular Ring Compression lb/in. CD	Modified Ring Compression lb/in. MD	Modified Ring Compression lb/in. CD
			38-lb Linerboard						
A	Virgin[b]	36.9	11.5	3.2	84	15.7	10.5	21.0	13.5
B	Virgin[b]	38.3	12.4	3.1	105	17.2	11.8	23.0	15.0
C	10	38.0	11.1	3.4	93	15.7	11.0	23.0	16.0
E	20	37.4	10.7	3.5	99	16.0	11.0	23.0	15.5
H	30	40.6	12.2	3.3	102	17.7	11.2	19.3	12.8
J	100	38.1	10.6	3.6	89	18.3	13.3	25.0	19.5
			69-lb Linerboard						
A	Virgin[b]	65.7	19.5	3.4	127	28.8	22.3	31.8	27.0
B	Virgin[b]	66.1	19.3	3.4	138	28.8	22.5	31.7	26.7
E	20	70.1	22.9	3.1	131	29.2	21.0	35.2	26.2
F	23	70.1	20.2	3.5	122	27.5	20.3	33.3	24.3
D	30	71.9	21.8	3.3	141	25.7	19.2	31.7	24.3

[a] FKBG liner base-line bursting strength averages were 97 and 142 psig for 38- and 69-lb liner, respectively.

[b] Manufactured from essentially 100% virgin kraft pulp.

TABLE VII

TENSILE PROPERTIES OF 38- AND 69-LB LINERBOARDS

Code	Approximate Recycled Fiber Content, %	Tensile Strength, lb/in. MD	Tensile Strength, lb/in. CD	Stretch, % MD	Stretch, % CD	Tensile Stiffness (Et), lb/in. MD	Tensile Stiffness (Et), lb/in. CD	Tensile Energy Absorption, ft lb/ft^2 MD	Tensile Energy Absorption, ft lb/ft^2 CD
				38-lb Linerboard					
A	Virgin[a]	77.0	27.1	1.42	3.88	8,550	2,560	8.0	9.3
B	Virgin[a]	86.0	33.3	1.21	2.89	9,970	3,320	7.9	8.4
C	10	72.7	31.5	1.41	3.94	8,340	2,977	7.4	11.5
E	20	86.7	30.2	1.82	3.74	8,842	3,000	12.2	10.1
H	30	95.5	29.0	1.45	3.21	10,453	2,825	10.1	8.3
J	100	79.0	29.2	1.61	4.87	8,340	2,854	9.4	13.2
				69-lb Linerboard					
A	Virgin[a]	93.4	54.6	1.24	3.66	11,400	5,040	8.8	18.5
B	Virgin[a]	110.0	60.8	1.16	2.66	13,900	5,950	9.4	13.6
E	20	115.0	52.8	1.72	3.85	12,900	5,040	16.1	18.6
F	23	97.1	50.3	1.48	2.93	11,500	4,990	10.9	12.7
D	30	108.0	49.4	1.69	2.72	12,100	5,010	15.2	11.4

[a]Manufactured from essentially 100% virgin kraft pulp.

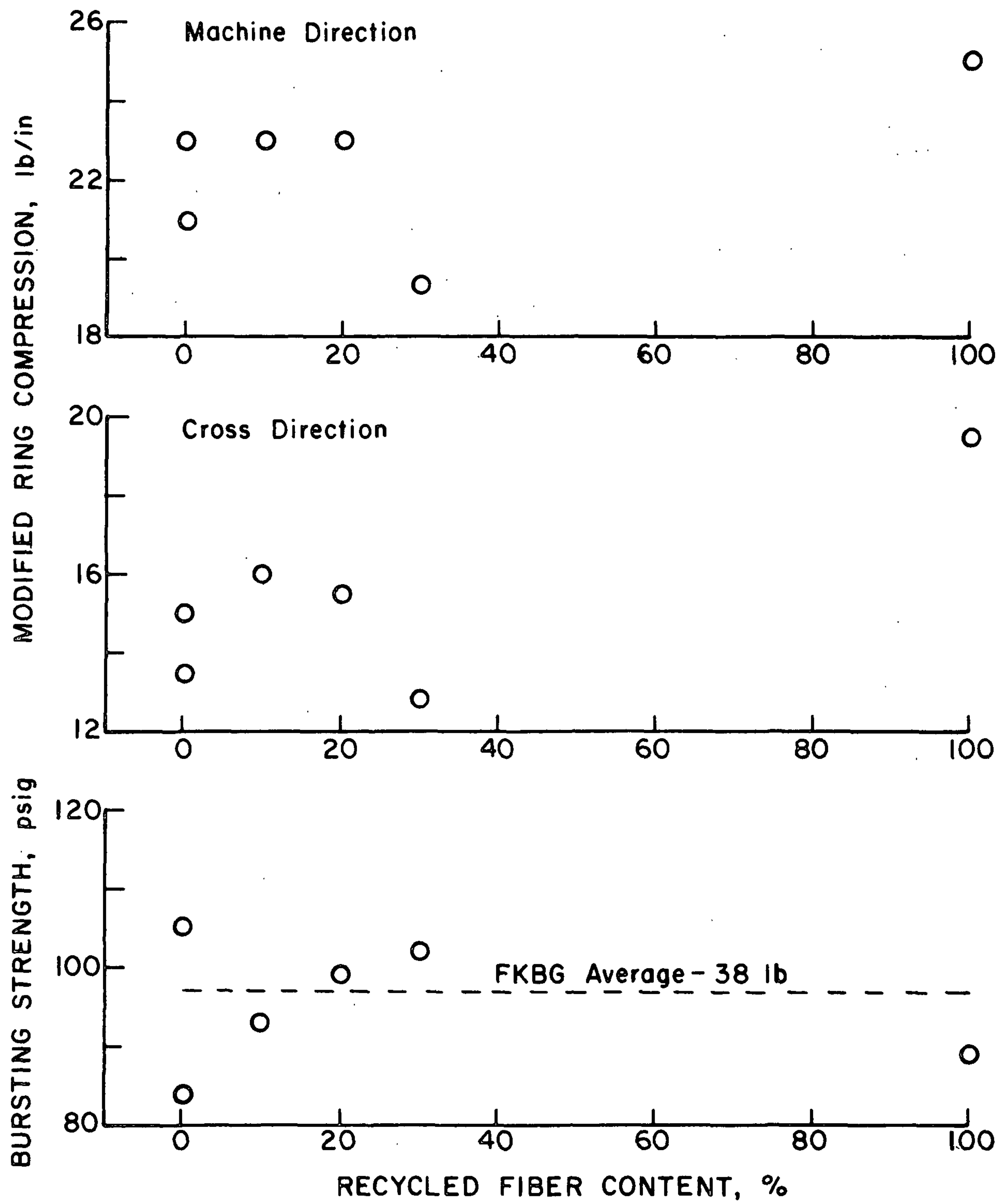


Figure 14. Bursting Strength and Edgewise Compression Results on 38-lb Linerboard

Therefore, on an overall basis, it appears that linerboards made with substantial amounts of recycled fiber of up to 100% will exhibit commercially satisfactory property levels when properly processed and manufactured. There is, perhaps, some tendency for boards with high recycled fiber content to exhibit lower bursting strengths. However, the edgewise compression strengths of boards made with high recycled fiber content are usually quite comparable to these for boards with little or no recycled fiber. This is particularly noteworthy because cross direction edgewise compression strength is the major property governing top load box compression performance.

AVAILABILITY OF RECYCLED FIBER

A systems analysis was carried out with the following objectives:

1. to determine on a regional basis the potential supply of OCC for recycling into kraft linerboard in 1980 and 1985, and
2. to assess the realistic ranges of recovery for OCC for use in linerboard on a regional basis considering recovery techniques, transportation, contaminants and economies for 1980 and 1985.

An abridged summary of the analysis of the potential supply of OCC and the physical limits on recovery is discussed in this section of the report. In the following section the limitations imposed on OCC recovery by economics, OCC quality and logistics of supply are analyzed. The sources of data are listed in Appendix I.

CONTAINERBOARD DEMAND AND CONSUMPTION

The first step in determining the amount of OCC which would be generated for any time period is to determine the quantity of containerboard which will be manufactured. Production figures from 1960-1975 and industry estimates for 1976 were used to project production amounts for 1977 through 1985. Since over 90% of containerboard is used for corrugated boxes, the box plant consumption of containerboard grades was similarly determined. The production data are shown in Table VIII and the total containerboard and linerboard data are illustrated in Fig. 15. Figure 15 shows that containerboard production is estimated to increase from about 17 million tons in 1976 to 22.5 million tons in 1985. The corresponding figures for linerboard are 11.5 and 15.2 million tons, respectively.

TABLE VIII

CONTAINERBOARD PRODUCTION (DOMESTIC), 1965-1985
(short tons)

Year	Linerboard	Corrugating Medium	Chip & Filler	Total Containerboard
1960	5,474,800	2,461,000	250,800	8,186,600
1961	5,753,900	2,649,300	258,100	8,661,300
1962	6,216,500	2,822,100	260,400	9,299,000
1963	6,414,000	2,961,800	262,500	9,638,300
1964	6,907,500	3,165,100	269,300	10,341,900
1965	7,480,600	3,438,200	280,300	11,199,100
1966	8,347,300	3,799,800	312,500	12,459,600
1967	8,215,600	3,743,500	289,500	12,248,600
1968	9,043,700	4,061,900	282,800	13,388,400
1969	9,692,400	4,395,400	308,600	14,396,400
1970	9,403,100	4,264,000	297,200	13,964,300
1971	9,530,800	4,519,700	302,500	14,353,000
1972	10,856,500	4,846,500	315,900	16,019,000
1973	11,355,900	5,255,000	317,100	16,928,100
1974	11,305,400	5,179,200	282,300	16,767,000
1975	9,854,200	4,449,300	282,600	14,586,200
1976a/	11,447,400a/	5,213,000a/	326,500a/	16,986,900a/
1977b/	12,130,000	5,540,000	320,000	17,990,000
1978b/	12,520,000	5,710,000	325,000	18,555,000
1979b/	12,900,000	5,890,000	325,000	19,115,000
1980b/	13,290,000	6,060,000	330,000	19,680,000
1985b/	15,220,000	6,940,000	345,000	22,505,000

a/ Estimated
b/ Projected

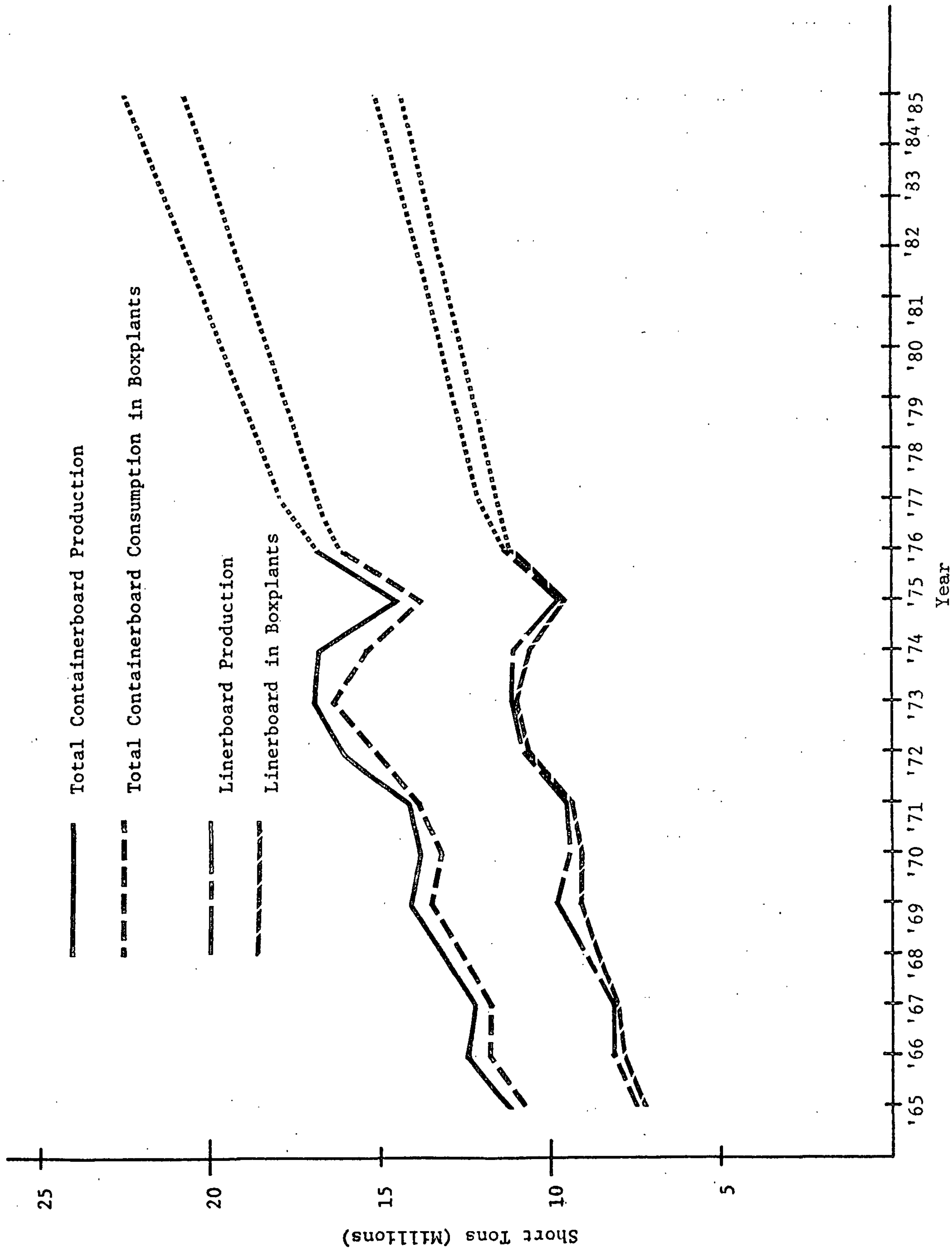


Figure 15. Containerboard and Linerboard Production and Consumption (Domestic) 1965-1985

OCC GENERATED BY REGION

Based on the above and population data, the amount of OCC generated within each of nine regions in the continental U.S.A. was estimated. This was done on the basis of retail and manufacturing employment, sales and industrial activity in each SMSA (Standard Metropolitan Statistical Area). These results are shown in Table IX and graphically illustrated in Fig. 16. There is a wide range between regions for OCC generation, especially in 1985 when the mountain and Pacific Region (Northern Division) is projected to generate only 0.7 million tons while the East North Central Region will generate more than 3.9 million tons.

REGIONAL CONTAINERBOARD RECYCLING TO 1985

Having estimated the regional generations of OCC, the next step is to project the regional consumption of OCC for existing (recycling) uses. This was done by analyzing the current utilization of OCC as a fiber furnish for paper and paperboard manufacturing (see Fig. 17) which indicates that 68% of recycled corrugated is used in recycled paperboard, corrugating medium and a small amount in linerboard. The 7% use on kraft paperboard is predominantly recycling of corrugated cuttings and OCC in kraft linerboard. The latter amounted to 343,000 tons in 1975.

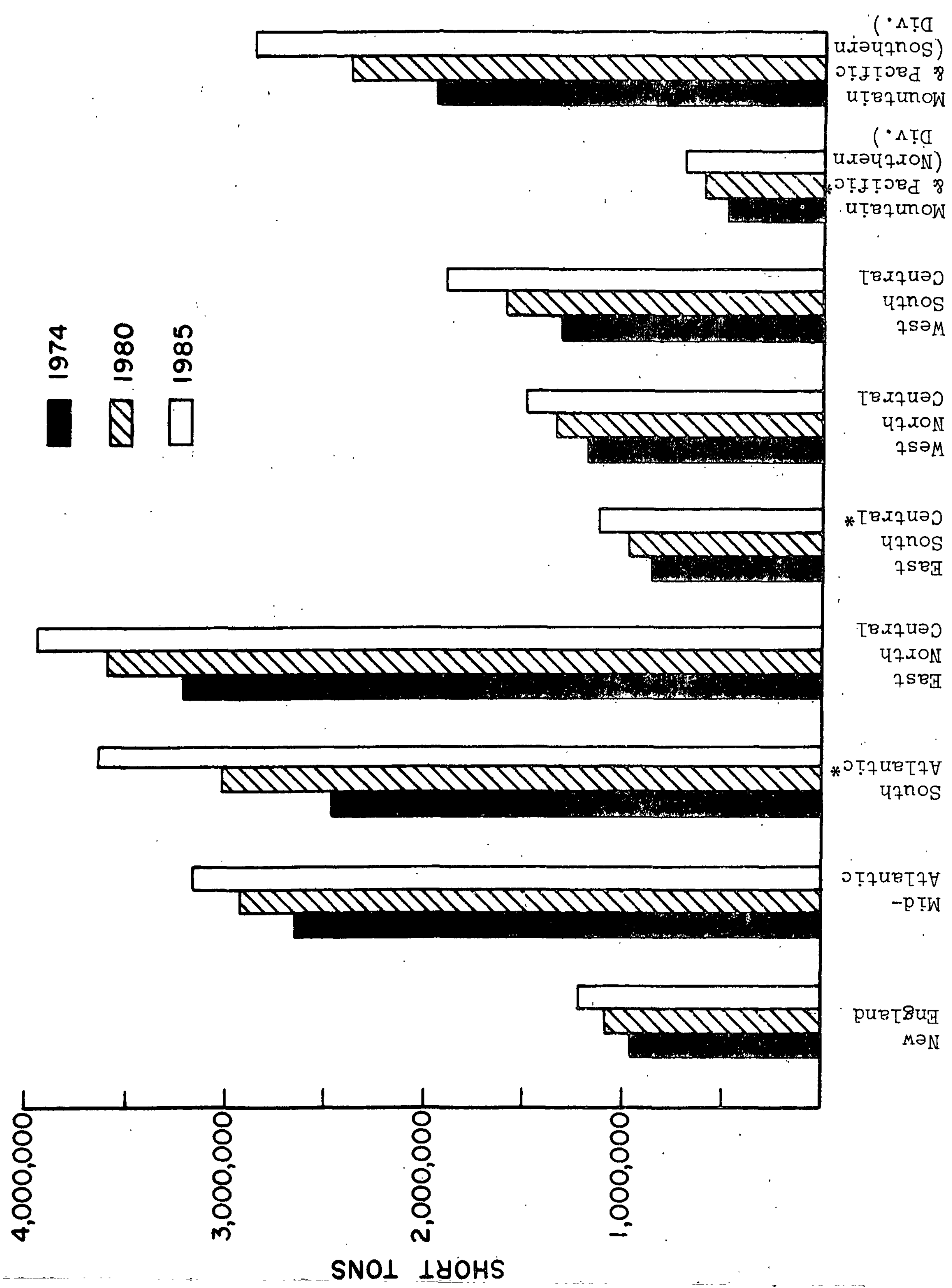
Total domestic OCC consumption for nonlinerboard* recycling is shown in Table X and Fig. 18 which indicates that total consumption of OCC rises from 4.4 million tons in 1974 to 8.5 million tons in 1985. Again there were significant

*The term nonlinerboard recycling is defined as the corrugated (clippings and OCC) currently or forecast to be used as a fiber furnish on all paperboard products including kraft linerboard under current trends. The term "kraft linerboard" is used to refer to incremental increases over the current level as a result of special recovery and recycling efforts.

TABLE IX

OLD CORRUGATED CONTAINERS GENERATED BY REGION, 1974-1985
(tons and percentage)

	New England	Mid-Atlantic	South Atlantic	East North Central	East South Central	West North Central	West South Central	Mountain and Pacific Northern Division	Mountain and Pacific Southern Divison	U.S. Total
1974										
Total in SMSAs	792,418	2,365,226	1,624,670	2,530,071	453,776	718,864	985,075	285,665	1,744,844	11,500,609
Percent of U.S. total	5.26	15.70	10.78	16.78	3.01	4.77	6.54	1.90	11.58	76.32
Total Other	168,819	290,701	840,465	674,377	384,123	466,517	333,292	203,547	206,149	3,567,490
Percent of U.S. total	1.12	1.92	5,58	4.48	2.55	3.10	2.21	1.35	1.37	23.68
REGIONAL TOTAL	961,237	2,655,927	2,465,135	3,204,448	837,899	1,185,381	1,318,367	489,212	1,950,993	15,068,599
Percent of U.S. total	6.38	17.62	16.36	21.26	5.56	7.87	8.75	3.25	12.95	100.00
1980										
Total in SMSAs	900,535	2,603,491	1,990,287	2,825,997	532,612	814,686	1,193,121	345,147	2,135,704	13,341,580
Percent of U.S. total	5.14	14.86	11.36	16.13	3.04	4.65	6.81	1.97	12.19	76.15
Total Other	190,969	318,866	1,030,184	755,118	452,019	529,108	404,715	245,282	252,290	4,178,551
Percent of U.S. total	1.09	1.82	5.88	4.31	2.58	3.02	2.31	1.40	1.44	23.85
REGIONAL TOTAL	1,091,504	2,922,357	3,020,471	3,581,115	984,631	1,343,794	1,597,836	590,429	2,387,994	17,520,131
Percent of U.S. total	6.23	16.68	17.24	20.44	5.62	7.67	9.12	3.37	13.63	100.00
1985										
Total in SMSAs	995,677	2,818,747	2,382,011	3,117,250	615,036	907,528	1,418,389	408,688	2,558,308	15,221,634
Percent of U.S. total	4.97	14.07	11.89	15.56	3.07	4.53	7.08	2.04	12.77	75.98
Total Other	214,561	346,584	1,234,078	831,400	522,881	590,995	478,806	290,489	302,509	4,512,103
Percent of U.S. total	1.07	1.73	6.16	4.15	2.61	2.94	2.39	1.45	1.51	29.02
REGIONAL TOTAL	1,210,038	3,165,331	3,616,089	3,948,650	1,137,917	1,498,523	1,897,195	699,177	2,860,817	20,033,737
Percent of U.S. total	6.04	15.80	18.05	19.71	5.68	7.48	9.47	3.49	14.28	100.00



*Kraft linerboard producing regions.

Figure 16. Old Corrugated Containers Generated by Region, 1974-1985

regional differences in "existing" consumption of OCC. Recycling mills using OCC as furnish tend to be relatively small and located close to their source of supply. They account for the large current OCC consumption in the East North Central and Mid-Atlantic Regions.

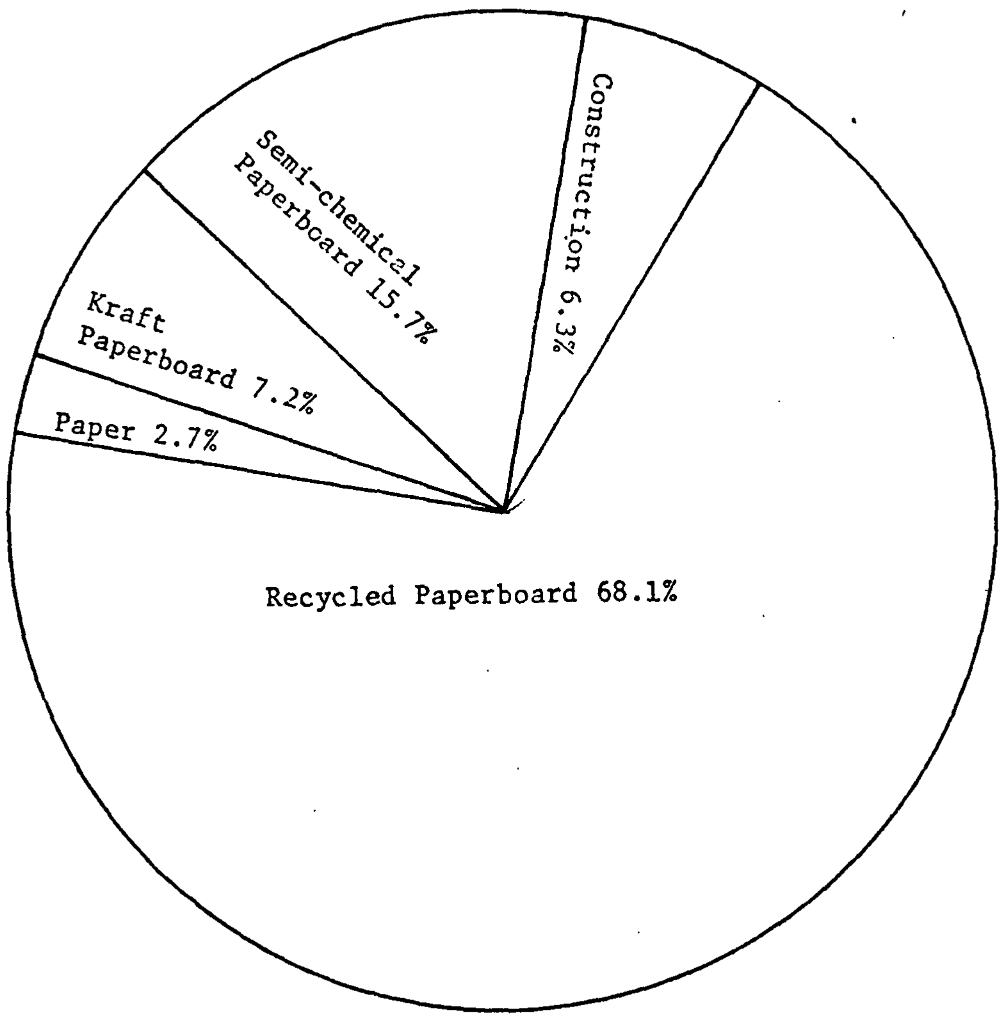


Figure 17. Corrugated (Container) Use in Paper and Paperboard Manufacture, 1975

TABLE X

SUMMARY OF REGIONAL DOMESTIC OCC CONSUMPTION FOR NON-LINERBOARD USES, 1974-1985
(000 tons)

	New England	Mid Atlantic	South Atlantic	East North Central	East South Central	West North Central	West South Central	Mountain and Pacific Northern Division	Mountain and Pacific Southern Division	U.S. Total
1974										
Total domestic OCC used	184	883	471	1,257	192	140	155	88	502	3,872
Plus exports	-	121	-	57	-	-	132	30	156	496
Total OCC consumption	184	1,004	471	1,314	192	140	287	118	658	4,368
1980										
Total domestic OCC used	264	1,247	953	1,710	337	156	234	136	768	5,805
Plus exports	-	197	-	119	-	-	60	46	236	658
Total OCC consumption	264	1,444	953	1,829	337	156	294	182	1,004	6,463
1985										
Total domestic OCC used	342	1,565	1,273	2,211	455	205	323	176	996	7,546
Plus exports	-	277	-	167	-	-	84	65	331	924
Total OCC consumption	342	1,842	1,273	2,378	455	205	407	241	1,327	8,470

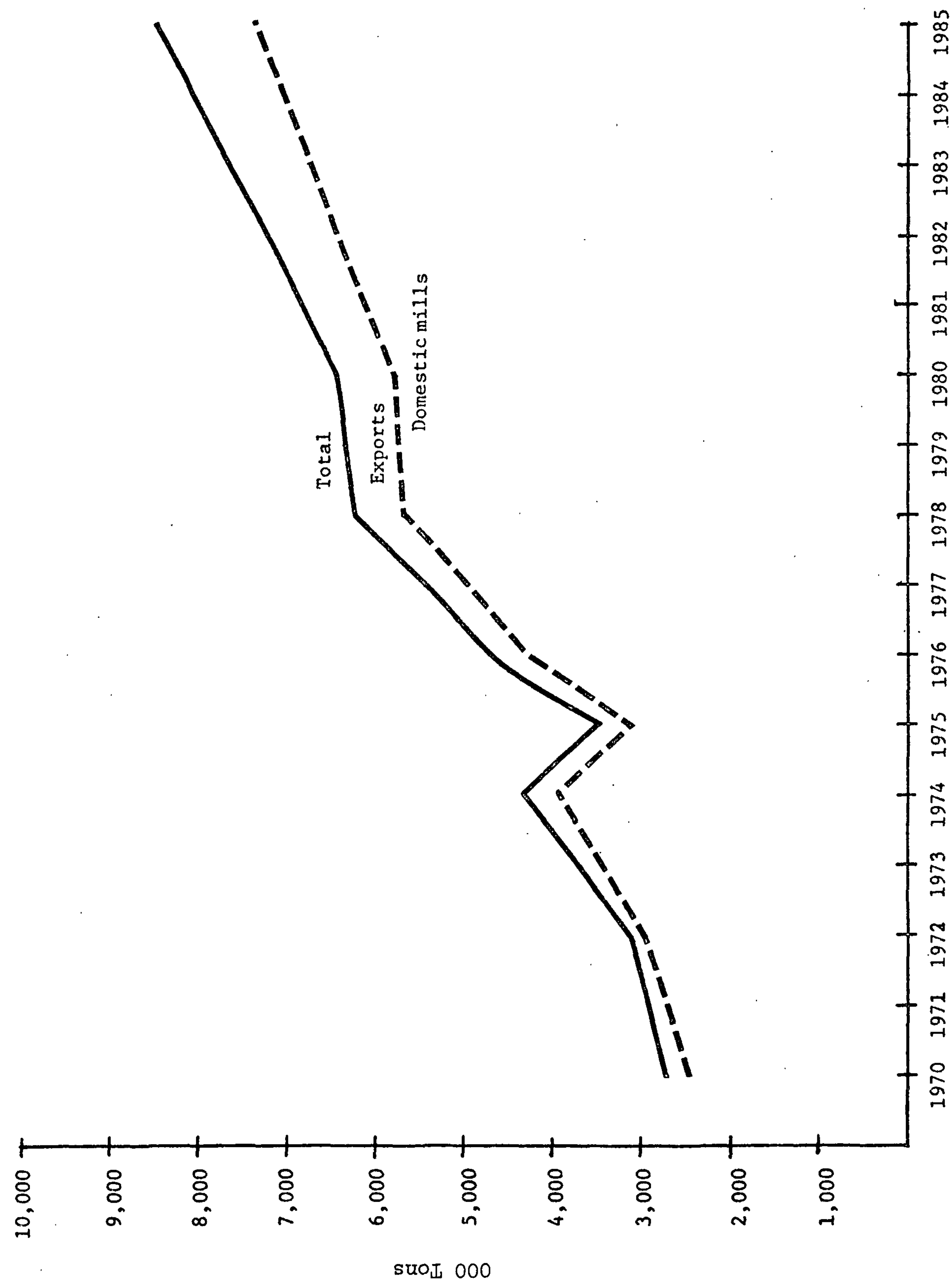


Figure 18. Old Corrugated Containers Recycled, 1970-1985

UNRECOVERED OCC TO 1985

Taking the regional projections for OCC generation and subtracting OCC consumption for "nonlinerboard" recycling gives the regional totals for the quantity of OCC that will be theoretically "available for recovery" and recycling into kraft linerboard over and above the base-line projections. The unrecovered OCC data are summarized in Table XI. By 1985 the amount of unrecovered OCC is projected to be about 11.6 million tons as compared to the 8.5 million tons of recovered OCC. Once again, wide regional differences are apparent.

KRAFT LINERBOARD CAPACITY TO 1985

Projections of kraft linerboard capacity to 1985 were made using data from the American Paper Institute. The results are presented on Table XII and Fig. 19. There is some linerboard production in the "empty" regions, however the API data lists no "kraft" linerboard capacity in the empty regions. Thus, for purposes of this analysis, the capacities shown in the four regions with kraft linerboard mills are considered the "target" areas for increased recycling of OCC into kraft linerboard.

RECOVERABILITY OF OCC TO 1985

Clearly not all of the unrecovered OCC is available for recovery and recycling. Most of the OCC that remains unavailable for recovery is made so by the economics of collection and transportation. If the OCC is generated in very small amounts (such as households) or at great distances from the recovery markets (such as nonmetropolitan areas), it is easier to discard the OCC than to recover it. Furthermore, the cost of transportation is a significant factor.

TABLE XI

UNRECOVERED OLD CORRUGATED CONTAINERS
(short tons)

	New England	Mid-Atlantic	South Atlantic	East North Central	East South Central	West North Central	West South Central	Mountain and Pacific Northern Division	Mountain and Pacific Southern Division	Total
1974										
OCC Generated	961,237	2,655,927	2,465,135	3,204,448	837,899	1,185,381	1,318,367	489,212	1,950,993	15,068,599
OCC Recovered	184,000	1,004,000	471,000	1,314,000	192,000	140,000	287,000	116,000	660,000	4,368,000
Unrecovered OCC	777,237	1,651,927	1,994,135	1,890,448	645,899	1,045,381	1,031,367	373,212	1,290,993	10,700,599
% of U.S. Total	7.26	15.44	18.64	17.67	6.04	9.77	9.64	3.49	12.06	100.00
1980										
OCC Generated	1,091,504	2,922,357	3,020,471	3,581,115	984,631	1,343,794	1,597,836	590,429	2,387,994	17,520,131
OCC Recovered	264,000	1,444,000	953,000	1,829,000	337,000	156,000	294,000	182,000	1,004,000	6,463,000
Unrecovered OCC	827,504	1,478,357	2,067,471	1,752,115	647,631	1,187,794	1,303,836	408,429	1,353,994	11,057,131
% of U.S. Total	7.48	13.37	18.70	15.85	5.86	10.74	11.79	3.69	12.52	100.00
1985										
OCC Generated	1,210,038	3,165,331	3,616,089	3,948,650	1,137,917	1,498,523	1,897,195	699,177	2,860,817	20,033,737
OCC Recovered	342,000	1,842,000	1,273,000	2,378,000	455,000	205,000	407,000	421,000	1,327,620	8,470,000
Unrecovered OCC	868,038	1,323,331	2,343,089	1,570,650	682,917	1,293,523	1,490,195	458,177	1,533,817	11,563,737
% of U.S. Total	7.51	11.44	20.26	13.58	5.91	11.19	12.89	3.96	13.26	100.00

TABLE XII

KRAFT LINERBOARD CAPACITY BY REGION, 1972-1985
(thousands of short tons)

Year	New England	Mid-Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain-Pacific Northern	Mountain-Pacific Southern	Total
1972	-	-	-	-	6,402	2,108	2,099	1,872	420	12,901
1973	-	-	-	-	6,196	2,203	2,107	1,892	420	12,818
1974	-	-	-	-	6,260	2,232	2,189	1,914	420	13,015
1975	-	-	-	-	6,303	2,339	2,321	1,901	431	13,294
1976	-	-	-	-	6,673	2,449	2,769	2,001	441	14,333
1977	-	-	-	-	6,643	2,541	2,702	1,998	452	14,336
1978	-	-	-	-	6,602	2,401	2,865	2,064	464	14,396
1979	-	-	-	-	6,767	2,461	2,937	2,116	475	14,756
1980	-	-	-	-	6,936	2,522	3,010	2,169	487	15,124
1981	-	-	-	-	7,110	2,585	3,085	2,223	499	15,502
1982	-	-	-	-	7,287	2,650	3,162	2,279	512	15,889
1983	-	-	-	-	7,469	2,716	3,241	2,336	525	16,286
1984	-	-	-	-	7,656	2,784	3,323	2,394	538	16,695
1985	-	-	-	-	7,848	2,854	3,405	2,454	551	17,112

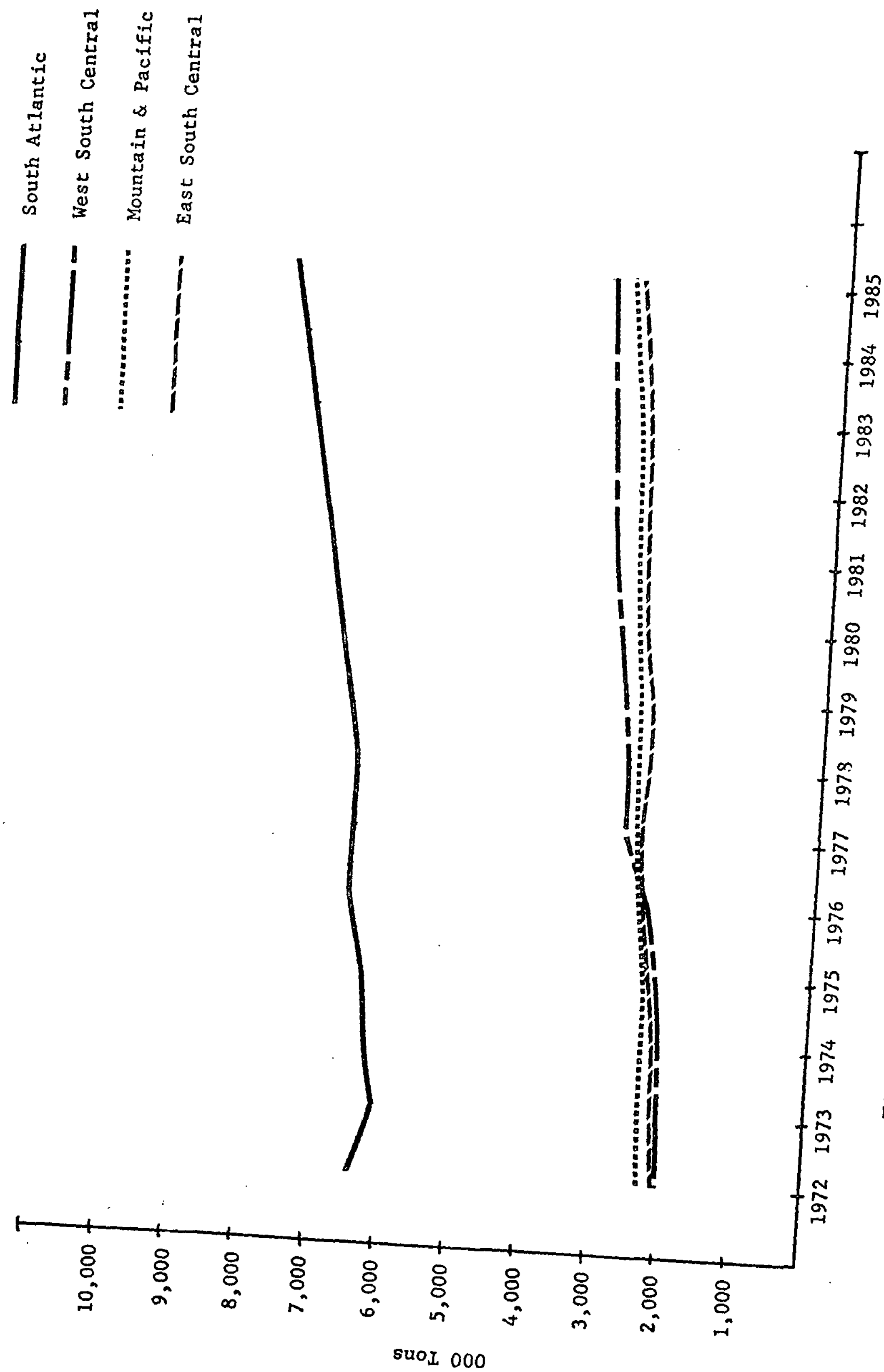


Figure 19. Kraft Linerboard Capacity by Region, 1972-1985

Based on such considerations it was estimated that the maximum recovery potential of the total amount of OCC generated in a region is 70%. The remaining 30% is assumed to be unavailable for recovery, lost to destruction, "permanent" applications, household and nonmetropolitan areas.

ANALYSIS OF ALTERNATIVE OCC RECYCLING RATES FOR KRAFT LINERBOARD TO 1985

The following assumptions were made at this stage (which are modified by economic considerations in the next section of the report):

a. Recovery techniques are available to reach a recovery level of 70% of OCC generated in a given region.

b. Quality of the recovered OCC is not a limitation to its recycling.

c. Interregional transfers are made as required to supply a linerboard-producing region up to the limits of recovery in each region.

d. The Law of Diminishing Returns is operative with recovery related to the availability of OCC and the percent remaining unrecovered at any given rate of recycling.

e. All regions are taken to the same level of recycling at the same time.

RECYCLING OF OCC INTO KRAFT LINERBOARD, 1985

Since kraft linerboard mills are located in only four of the nine regions, these regions were designated the "kraft linerboard-producing regions" or "OCC consuming regions." At the same time, all nine regions are "OCC supplying regions," with transfer taking place from "nonlinerboard" regions to linerboard-producing regions.

By definition, the base line recycling of OCC for "nonlinerboard" applications was not changed. Thus, the potential supply of OCC kraft linerboard mills becomes the unrecovered but recoverable quantity of linerboard for any region. Interregional transfers take place as allowed for in the calculations.

The "new" recycling rate was based upon the kraft linerboard capacity in the producing region. The following rates were analyzed for 1985: 10, 20 and 30%.

The results for 1985 are given in Tables XIII through XV, and Fig. 20 through 22. Table XIII shows a recycling rate of 10% of kraft linerboard capacity in each of the four regions. The "demand" for OCC is given in the "OCC requirement" column; this demand is satisfied by new OCC recovery in that same region first, then the next adjacent (nonlinerboard producing) region.

Even at 10% recycling, it takes two regions to supply OCC for the OCC consuming regions (Table XIII). For instance, the South Atlantic Region has an OCC requirement of about 785,000 tons. This is satisfied by 623,000 tons from the same region (South Atlantic) and 122,000 tons from the Mid-Atlantic Region (Table XIII).

The nonliner use of OCC in this region is 1,273,000 tons; thus, total recovery in 1985 is 1,935,000 tons from the South Atlantic Region, or 53.5% of the OCC generated in the region.

Tables XIV and XV take the recycling rate up to 30%. In Table XV the limits of OCC recycling in kraft linerboard are reached at 30%. In this table it can be seen that most regions have a recovery rate of 65 to 70%.

TABLE XIII

POTENTIAL RECOVERY AND CONSUMPTION OF OLD CORRUGATED CONTAINERS, 1985
At a recovery rate of 10% kraft linerboard capacity
(tons and percent)

OCC Consuming Regions (Linerboard)

Kraft Linerboard Producing Region	OCC Recovery Requirement (Kraft Linerboard)	Recovery of OCC by Supplying Region: New England	Mid-Atlantic	South Atlantic	East North Central	East South Central	West North Central	West South Central	Mountain Pacific (Northern)	Mountain Pacific (Southern)
South Atlantic Recovered for Liner (tons)	784,800	-	122,108	622,692	-	-	-	-	-	-
East South Central Recovered for Liner (tons)	285,400	-	-	-	128,542	156,858	-	-	-	-
West South Central Recovered for Liner (tons)	340,500	-	-	-	-	-	32,447	308,053	-	-
Mountain/Pacific (Northern) Recovered for Liner (tons)	300,500	-	-	-	-	-	-	-	117,608	182,892
Total Four Regions Recovered for Liner (tons)	1,711,200	-	122,108	662,692	128,542	156,858	32,447	413,726	117,608	182,892
% of Regional OCC Generated			(3.86)	(18.33)	(3.26)	(13.78)	(2.17)	(16.24)	(16.82)	(6.39)
Total (Non Liner-board Recovery (tons)	8,470,000	342,000	1,842,000	1,273,000	2,378,000	455,000	205,000	407,000	241,000	1,327,000
% of Regional OCC Generated		(28.26)	(58.19)	(35.20)	(60.22)	(39.99)	(13.68)	(21.45)	(34.47)	(46.39)
Grand Total Recovered (tons)	10,181,200	342,000	1,964,108	1,935,692	2,506,542	611,858	237,447	715,053	358,608	1,509,892
% of Regional OCC Generated		(28.26)	(62.05)	(53.53)	(63.48)	(53.77)	(15.85)	(37.69)	(51.29)	(52.78)

TABLE XIV

POTENTIAL RECOVERY AND CONSUMPTION OF OLD CORRUGATED CONTAINERS, 1985
At a recovery rate of 20% kraft linerboard capacity
(tons and percent)

OCC Consuming Regions (Linerboard)

Kraft Linerboard Producing Region	OCC Recovery Requirement (Kraft Linerboard)	Recovery of OCC by Supplying Region: New England	Mid-Atlantic	South Atlantic	East North Central	East South Central	West North Central	West South Central	Mountain Pacific (Northern)	Mountain Pacific (Southern)
South Atlantic Recovered for Liner (tons)	1,569,600	173,312	289,178	1,107,110	-	-	-	-	-	-
East South Central Recovered for Liner (tons)	570,800	-	-	-	233,980	250,964	85,856	-	-	-
West South Central Recovered for Liner (tons)	681,000	-	-	-	-	-	172,603	508,397	-	-
Mountain/Pacific (Northern) Recovered for Liner (tons)	601,000	-	-	-	-	-	43,437	-	183,400	374,163
Total Four Regions Recovered for Liner (tons)	3,422,400	173,312	289,178	1,107,110	233,980	250,964	301,896	508,397	183,400	374,163
% of Regional OCC Generated		(14.32)	(9.14)	(30.62)	(5.93)	(22.05)	(20.15)	(26.80)	(26.23)	(13.08)
Total (Non Linerboard Recovery (tons)	8,470,000	342,000	1,842,000	1,273,000	2,378,000	455,000	205,000	407,000	241,000	1,327,000
% of Regional OCC Generated		(28.26)	(58.19)	(35.20)	(60.22)	(39.99)	(13.68)	(21.45)	(34.47)	(46.39)
Grand Total Recovered (tons)	11,892,400	515,312	2,131,178	2,380,110	2,611,980	705,964	506,896	915,397	424,400	1,701,163
% of Regional OCC Generated		(42.59)	(67.33)	(65.82)	(66.15)	(62.04)	(33.83)	(48.25)	(60.70)	(59.46)

TABLE XV

POTENTIAL RECOVERY AND CONSUMPTION OF OLD CORRUGATED CONTAINERS, 1985
At a recovery rate of 30% kraft linerboard capacity
(tons and percent)

OCC Consuming Regions (Linerboard): Kraft Linerboard Producing Region	OCC Recovery Requirement (Kraft Linerboard)	Recovery of OCC by Supplying Region: New England	Mid-Atlantic	South Atlantic	East North Central	East South Central	West North Central	West South Central	Mountain Pacific (Northern)	Mountain Pacific (Southern)
South Atlantic Recovered for Liner (tons)	2,354,400	466,152	366,644	1,246,690	274,914	-	-	-	-	-
East South Central Recovered for Liner (tons)	856,200	-	-	-	110,746	291,132	454,322	-	-	-
West South Central Recovered for Liner (tons)	1,021,500	-	-	-	-	-	352,411	669,089	-	-
Mountain/Pacific (Northern) Recovered for Liner (tons)	901,500	-	-	-	-	-	37,083	-	210,738	653,679
Total Four Regions Recovered for Liner (tons)	5,133,600	466,152	366,644	1,246,690	385,660	291,132	843,816	669,089	210,738	653,679
% of Regional OCC Generated		(38.52)	(11.58)	(34.48)	(9177)	(25.58)	(56.31)	(35.27)	(30.14)	(22.85)
Total (Non Linerboard Recovery (tons)	8,470,000	342,000	1,842,000	1,273,000	2,378,000	455,000	205,000	407,000	241,000	1,327,000
% of Regional OCC Generated		(28.26)	(58.19)	(35.20)	(60.22)	(39.99)	(13.68)	(21.45)	(34.47)	(46.89)
Grand Total Recovered (tons)	13,603,600	808,152	2,208,644	2,519,690	2,763,660	746,132	1,048,816	1,076,089	451,738	1,980,679
% of Regional OCC Generated		(66.79)	(69.78)	(69.68)	(69,99)	(65.57)	(69.99)	(56.72)	(64.61)	(69.23)

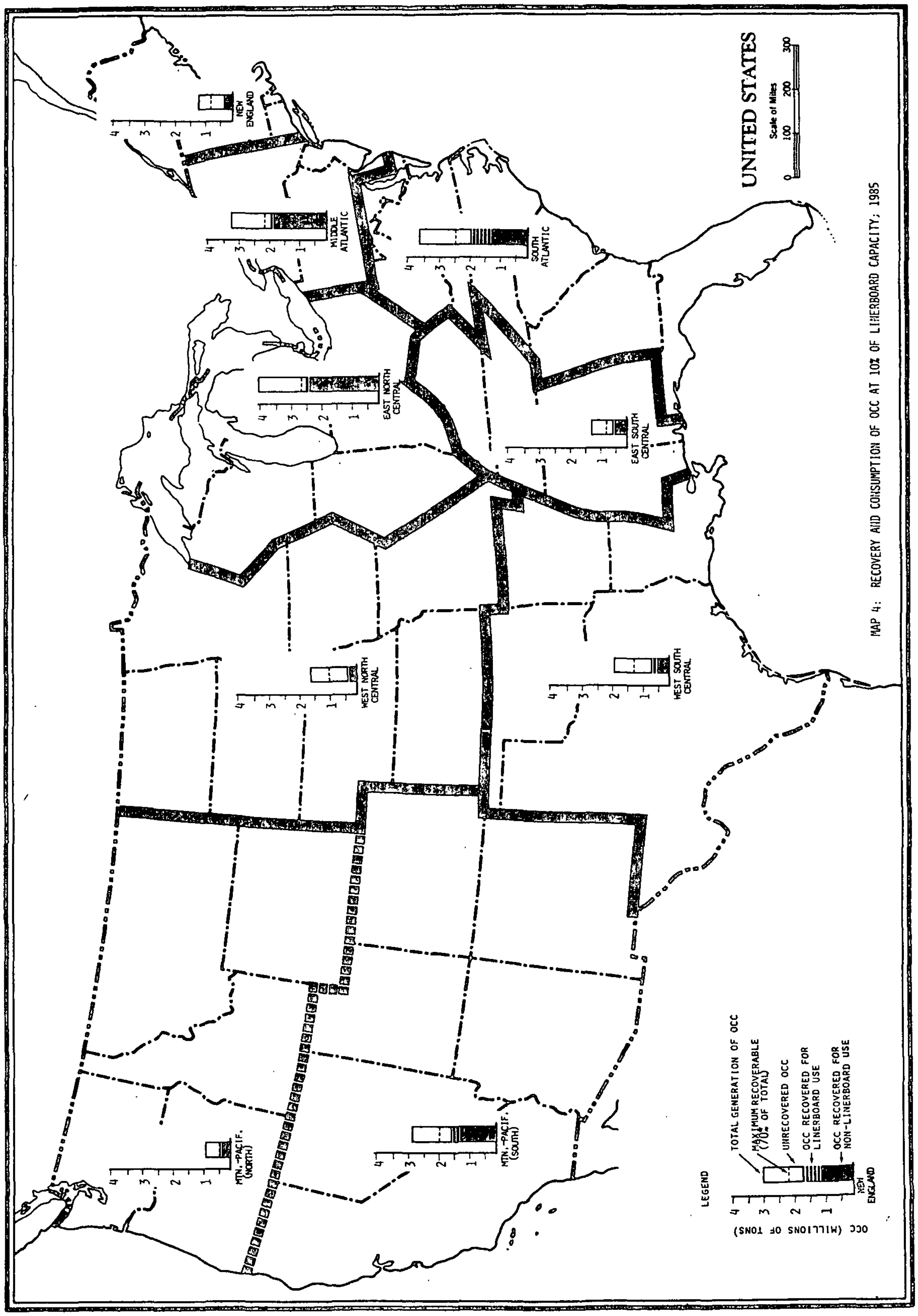


Figure 20. Recovery and Consumption of OCC at 10% of Linerboard Capacity, 1985

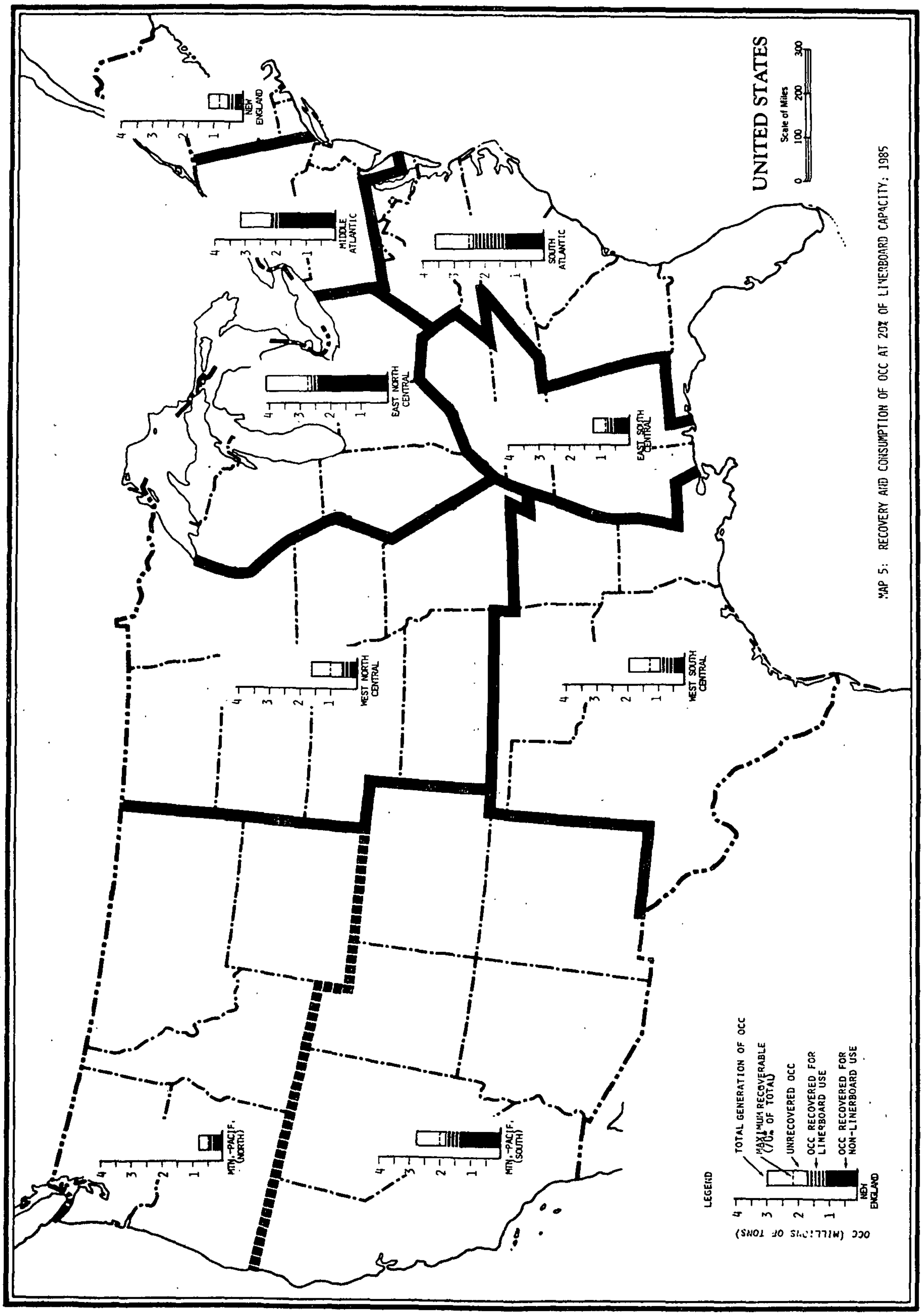


Figure 21. Recovery and Consumption of OCC at 20% of Linerboard Capacity, 1985

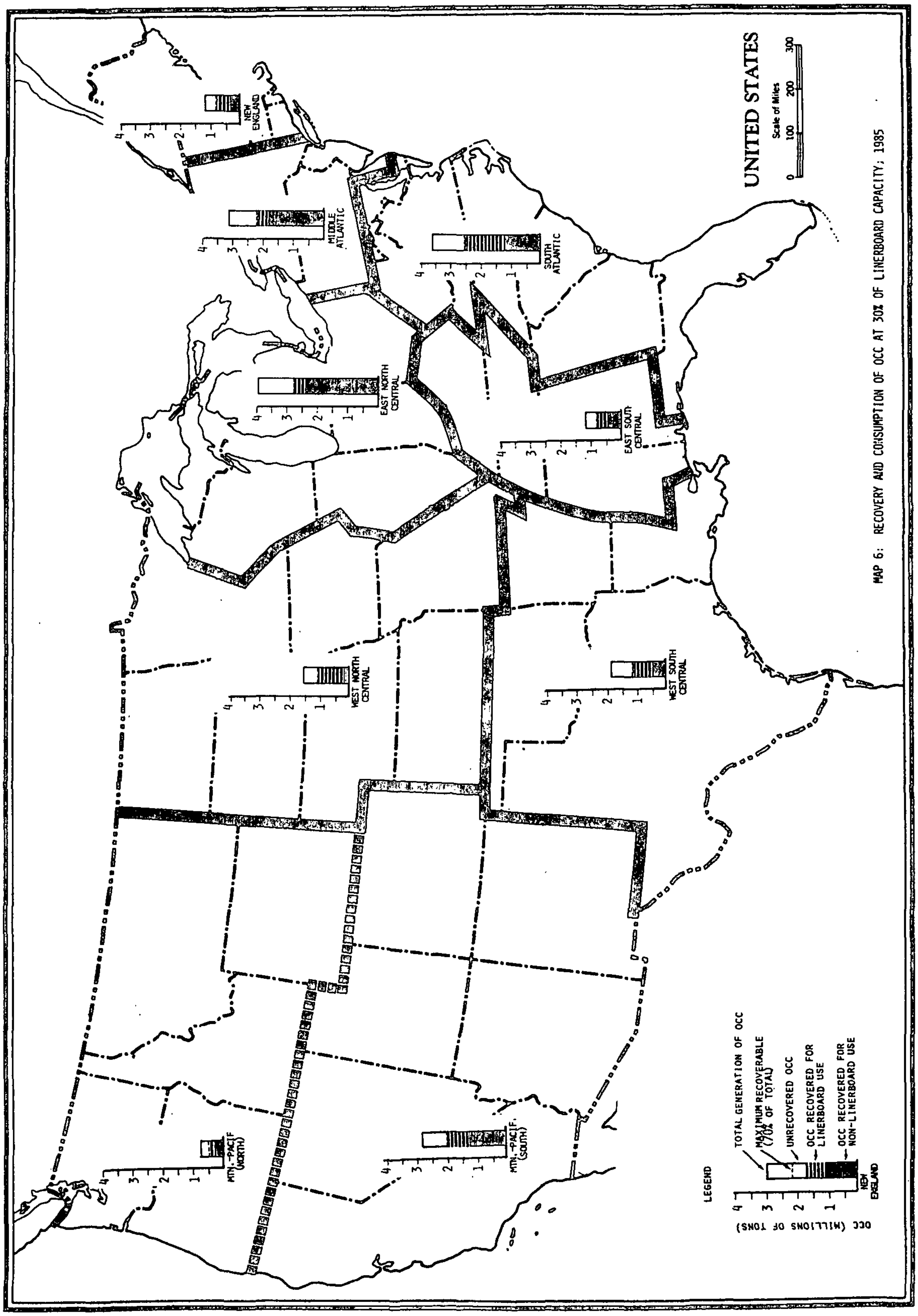


Figure 22. Recovery and Consumption of OCC at 30% of Linerboard Capacity, 1985

Taking the South Atlantic Region again, it shows an OCC requirement for 2,350,000 tons (30% of kraft linerboard capacity). This requirement is satisfied by 1,247,000 tons from the same region; 275,000 tons from the East North Central; 367,000 tons from the Mid-Atlantic; and 466,000 tons from New England. Thus, this illustrates that to recycle into linerboard at 30% in the South Atlantic Region essentially one-half the regions in the U.S.A. must supply OCC and that recovery is very intensive. The same is true for the other kraft linerboard-producing regions.

For 1985 the analysis shows that a maximum of about 5,100,000 tons of OCC could be recycled into linerboard and that the maximum feasible recycling rate is 30% of kraft linerboard capacity. This is the recovery limit without adjustment for economics, quality, and logistics of supply.

Having calculated the limits of recoverability and recycling, it is now possible to further define these limits by considering other important parameters — economics, OCC quality, and logistics of supply. This is done in the following section.

IMPACT OF ECONOMICS ON POTENTIAL RECYCLING

In the previous section, the physical limits on OCC recovery for recycling into linerboard were analyzed. The results indicated that the limit on recycling is about 5.1 million tons in 1985. This section considers the impact of economics, quality and transportation.

TRANSPORTATION CONSIDERATION

Generally, each region can supply much of its own requirements by shipping 50-250 miles. However, as the recycling rate increases, shipments of 500 or more miles may become necessary to obtain supplies from other regions. If a mill is using rail shipments, OCC shipping costs are probably in the range of $10-12 per ton. The rates may be as much as $28-30 per ton for long hauls by rail.

Based on these considerations rail rates were analyzed for selected origins and destinations so as to allow for interregional shipments as the recovery rate is increased. The results indicate that transportation costs would be expected to rise from $10-12 per ton for the status quo recycling rate to $20-22 per ton at a 30% national average rate.

RECOVERY TECHNIQUES AND OCC QUALITY

At present, recycled fiber dealers seek out the relatively high volume "clean" sources such as auto assembly plants and retail food stores. However, in places like southern California where the recovery level is high and exports are common, the quality of recovered OCC is lower than inland locations.

To increase the recovery rate substantially it appears the following would take place. At relatively "modest" increases in demand new large volume clean sources would be located by recycled fiber dealers but they would generally represent the last "clean" retail and industrial sources. As the recovery rate rises, less desirable sources would be tapped — both in metropolitan and outstate locations. Also, dealers would need to replace outdated processing equipment and be capable of shipping high density bales for long distances.

Thus, as the recycling rate increases, it appears that linerboard producers and recyclers should be prepared to process in the mill a more heavily contaminated OCC supply. "Clean" sources would still predominate but control of these supplies would cause pressures on selling prices.

In an effort to allow for extra mill processing costs it was estimated that pulping and cleaning costs would increase from about \$20 to \$35 as the recycling rate increased from 0 (status quo) to 30%.

COST TRENDS FOR OCC

Recycled fiber prices are very sensitive in the short run to incremental changes in demand. However, it can be concluded there is a long-term base cost for OCC "marked" by the commodity action of the market.

The long-term cost level for OCC is estimated to be \$35-40 per ton. As the recovery rises to accommodate increased recycling into linerboard, the cost can be expected to rise also. The price vs. recovery rate curve is unknown. However, cost will probably rise proportionally to increased recovery at low rates and then increase sharply as recovery limits are approached — a reflection of the "Law of Diminishing Returns."

Such a cost curve was developed for OCC based upon an intuitive analysis of recovery rates and price action. It was estimated that the cost of OCC would rise from a base line of $35-40 per ton to $70-80 per ton at 30% recycling of OCC into kraft linerboard. While there is no quantitative evidence of this projected cost movement, it appears to be reasonable although the exact levels could be somewhat higher or lower.

ECONOMIC IMPACT — SYNTHESIS

The economic analysis, including consideration of the above factors, is summarized in Table XVI. For comparison purposes virgin kraft pulp costs were estimated to range from $75-100. Table XVI shows that OCC recycling is feasible to about 15% recycling. However, the economics are estimates and, hence, some range of 10 to 20% is more realistic. A natural average recycling rate of 20% is equivalent to the utilization of 3.4 million tons of OCC in 1985. Thus, it appears that OCC could be used in linerboard in amounts ranging from 3.4 to 5.1 million tons in 1985, depending on both availability and cost.

The above analysis does not consider capital requirements which favor recycled fiber use. The Midwest Research Institute's report on "The Impact of Contaminants" estimated capital savings of $40,000 per daily ton for the supplemental use of recycled fiber in linerboard and $55,000 per ton for recycled fiber mills. Such capital savings would promote higher recycling rates than above.

While most high quality high volume sources of OCC are presently being tapped there are still significant quantities of "clean" OCC yet unrecovered. It appears that by utilizing these "clean" sources of OCC, natural average recycling rates of 10 to 20% into linerboard may be feasible depending on regional circumstances.

TABLE XVI

ECONOMIC ANALYSIS OF RECYCLING OCC INTO LINERBOARD
(At 0 to 30% of linerboard capacity)

Category of Cost*	OCC Recycling Rate in Kraft Linerboard						
	Status Quo (0%)	5%	10%	15%	20%	25%	30%
Mill cost for OCC - $/ton	35 to 40	37 to 42	39 to 44	42 to 48	45 to 52	52 to 60	70 to 80
Transportation cost - $/ton	10 to 12	11 to 14	12 to 16	15 to 18	16 to 20	18 to 20	20 to 22
Delivered cost of OCC - $/ton	45 to 52	48 to 56	51 to 60	57 to 66	61 to 72	70 to 80	90 to 102
Estimated Average Cost - $/ton	48	52	55	61	66	75	96
Adjustment for yield of 85 to 92% - $/ton	52	57	61	69	76	87	113
Mill pulping and cleaning - $/ton (estimated)	20	22	24	26	28	30	35
Total (OCC) pulp costs - $/ton	72	79	85	95	104	117	148
Advantage to OCC ± $/ton (kraft pulp @ $75 to $100/ton slush pulp)	+3 to +28	-4 to +21	-10 to +15	-20 to +5	-29 to -4	-42 to -17	-73 to -48

* All costs are estimated.

For example, it may be possible for the mills in the West South Central Region to exceed even 25% OCC furnish in the average.

The national average might be boosted to 15 to 25% if enough time is allowed for OCC dealers to cultivate additional sources of OCC. Judging from the 1973-1974 "boombust" of OCC costs, it seems that one to one and a half years lead time is necessary to develop new supplies for OCC.

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APPENDIX I

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